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Development of Aircraft Lavatory Compartments with Improved Fire Resistance Characteristics – Phase II

Sandwich Panel Resin System Development

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16 Abstract

This report describes a NASA-funded program to develop a resin system for use in the construction of lavatory wall panels, sidewall panels, and ceiling panels possessing flammability, smoke and gas emission, and toxicity (FS&T) characteristics superior to the existing epoxy resin. Candidate resins studied were phenolic, polyimide, and bismaleimide. Based on the results of a series of FS&T as well as mechanical and aesthetic property tests, a phenolic resin was chosen as the superior material. Material and process specifications covering the phenolic resin based materials were prepared and a method of rating sandwich panel performance, based on the tests performed in Task 2, was developed.

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CONTENTS

CONTENTS (Continued)

CONTENTS (Concluded)

TABLES

TABLES (Continued)

TABLES (Concluded)

FIGURES

FIGURES (Continued)

FIGURES (Continued)

FIGURES (Concluded)

DEVELOPMENT OF AIRCRAFT LAVATORY COMPARTMENTS WITH IMPROVED FIRE RESISTANCE CHARACTERISTICS – PHASE II

SANDWICH PANEL RESIN SYSTEM DEVELOPMENT

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1.0 SUMMARY

Phenolic, bismaleimide, and polyimide systems were studied as alternatives to the current flame-retarded epoxy used as the face sheet/adhesive resin. These candidate resins were chosen because of their inherent chemical stability under flaming conditions as opposed to the epoxy resins, which use halogen compounds to reduce flammability.

Polyimide/polyamide and polyimide/fiberglass honeycomb cores were tested as substitutes for the phenolic/polyamide currently used. Foam-filled honeycomb was investigated as an improved fire barrier.

Alternative decorative films were investigated as replacements for the polyvinyl chloride and polyvinyl fluoride currently used. Flame-modified polyvinyl fluoride, polyvinylidene fluoride, polycarbonate, and polyethersulfone were studied for flammability, smoke emission, toxic gas emission, and suitability as a printing surface for the decorative acrylic ink system.

This program consisted of five tasks. The first four tasks studied individual components of the sandwich panel and screened the various alternative concepts. The fifth task selected a complete sandwich system, which combined the elements of the previous tasks, and verified that the completed sandwich assemblies represented an improvement in flammability characteristics.

Task 1 was a phenolic sandwich development phase during which resins were optimized using basic flammability and mechanical tests. Task 2 was a comprehensive development phase during which phenolic, bismaleimide, and polyimide panels were compared with baseline epoxy resins. From this task, a phenolic system was selected for validation testing in Task 5. Task 3 was a decorative film development phase from which a polyvinyl fluoride/acrylic ink/polyvinyl fluoride (PVF/PVF) and a polyvinyl fluoride/acrylic ink/polycarbonate (PVF/PC) were selected for testing in Task 4. Task 4 verified that the PVF/PVF was compatible with all the face sheet resin systems, adhesives, and ink system, but that the PVF/PC was not. Task 5 verified that the completed decorative sandwich (viz., phenolic resin and PVF/PVF film) has improved flammability characteristics when compared to the baseline epoxy system.

Material and process specifications were prepared and a method of rating sandwich panel performance, based on the tests performed in Task 2, was developed.

2.0 INTRODUCTION

The Federal Aviation Administration (FAA) has proposed new regulations to control the smoke and toxic gas emission characteristics of commercial aircraft interiors (refs. 1 and 2). Large-scale tests conducted by the National Aeronautics and Space Administration—Johnson Space Center (NASA-JSC) have demonstrated that it may be possible to obtain improvements through the use of newly developed materials (refs. 3 and 4). Advances in polymer technology have made it desirable to conduct laboratory research to determine the extent of improvement that could be expected with these newly developed materials. A great deal of research effort has already been expended in this area; i.e., flammability studies and thermomechanical characterization of aircraft interior materials (refs. 5-12).

Sandwich panels are extensively used in wide-body aircraft interiors because of their inherent stiffness-to-weight ratio. As an example, the Boeing Model 747-200 has over 223 m^2 (2400 ft^2) of sidewall, 279 m^2 (3000 ft^2) of ceiling, and 111 m^2 (1200 ft^2) of lavatory and galley sandwich panels (fig. 1). These sandwich panels are as fire resistant as current technology permits. However, the extensive use of these panels does make it imperative that there be a continued effort to improve their fire resistance This is the area in which this development effort is concentrated. Nevertheless, the basic flammability, thermophysical, and mechanical properties must be measured and understood before material or design changes are made.

This report finalizes the results of a National Aeronautics and Space Administration—Ames Research Center (NASA-ARC) contract with the Boeing Commercial Airplane Company (ref. 13) to examine the fire characteristics of sandwich panels using lavoratory-scale test procedures. This program was funded by NASA-ARC as a part of their continuing aircraft flammability studies. The program examined the fire characteristics of sandwich panels using laboratory-scale test procedures. Alternative face sheet resins, decorative films, and honeycomb core materials were studied. The program had the multiple objectives of improving flammability, smoke emission, and toxic gas emission characteristics of sandwich panels while not sacrificing mechanical or aesthetic qualities of the panels.

3.0 SYMBOLS AND ABBREVIATIONS

A	Area
A_1	Normalized composite LOI
A_2	Normalized composite smoke emission (NBS chamber)
A_3	Normalized composite toxic gas emission (NBS chamber)
A_4	Normalized composite total heat release (Boeing Burn Through)
A_5	Normalized composite maximum heat release rate (Boeing Burn Through)
A_6	Normalized composite backface temperature rise (Boeing Burn Through)
A_7	Normalized composite total heat release (OSU-Vertical)
A_8	Normalized composite total heat release (OSU-Horizontal)
A_9	Normalized composite maximum heat release rate (OSU-Vertical)
A_{10}	Normalized composite maximum heat release rate (OSU-Horizontal)
A_{11}	Normalized composite smoke emission (OSU-Vertical)
A_{12}	Normalized composite smoke emission (OSU-Horizontal)
A_{13}	Normalized composite total heat release (DTA)
A_{14}	Normalized composite peel strength
A_{15}	Normalized composite flatwise tensile strength
A_{16}	Normalized composite impact strength
A_{17}	Normalized composite density
A_{18}	Normalized composite material and fabrication costs
A1	Normalized composite total heat release (OSU-Vertical)
A2	Normalized composite maximum heat release rate (OSU-Vertical)
A3	Normalized composite smoke emission (OSU-Vertical)
A4	Normalized composite total heat release (Boeing Burn Through)
A5	Normalized composite maximum heat release rate (Boeing Burn Through)
A6	Normalized composite backface temperature rise (Boeing Burn Through)
A7	Normalized composite material cost
A_{LT}	Normalized composite value based on laboratory testing
A_T	Normalized total overall assessment
AD	LOI of adhesive
ALC_{50}	Apparent Lethal Concentration for 50 percent mortality
ALT	Normalized composite value based on laboratory testing
Am	American
Aminco	American Instrument Company
ANPRM	Advance Notice of Proposed Rule Making
Ariz	Arizona
ASTM	American Society for Testing and Materials
AT	Normalized total overall assessment
Ave	Avenue
B	Weight of specimen after burnout
B_1	Normalized composite LOI
B_2	Normalized composite smoke emission (NBS chamber)
B_3	Normalized composite toxic gas emission (NBS chamber)
B_4	Normalized composite total heat release (Boeing Burn Through)
B_5	Normalized composite maximum heat release rate (Boeing Burn Through)
B_6	Normalized composite backface temperature rise (Boeing Burn Through)

B_7	Normalized composite total heat release (OSU-Vertical)
B_8	Normalized composite total heat release (OSU-Horizontal)
B_9	Normalized composite maximum heat release rate (OSU-Vertical)
B_{10}	Normalized composite maximum heat release rate (OSU-Horizontal)
B_{11}	Normalized composite smoke emission (OSU-Vertical)
B_{12}	Normalized composite smoke emission (OSU-Horizontal)
B_{13}	Normalized composite total heat release (DTA)
B_{14}	Normalized composite peel strength
B_{15}	Normalized composite flatwise tensile strength
B_{16}	Normalized composite impact strength
B_{17}	Normalized composite density
B_{18}	Normalized composite material and fabrication costs
B1	Normalized composite total heat release (OSU-Vertical)
B2	Normalized composite maximum heat release rate (OSU-Vertical)
B3	Normalized composite smoke emission (OSU-Vertical)
B4	Normalized composite total heat release (Boeing Burn Through)
B5	Normalized composite maximum heat release rate (Boeing Burn Through)
B6	Normalized composite backface temperature rise (Boeing Burn Through)
B7	Normalized composite material cost
B_{LT}	Normalized composite value based on laboratory testing
B_T	Normalized total overall assessment
BFR	Time in seconds to reach 538°C (1000°F)
BFT	Backface temperature at the end of 4.0 minutes
BLT	Normalized composite value based on laboratory testing
BMI	Bismaleimide
BP	LOI of bond ply
BT	Normalized total overall assessment
BTR	Maximum heat release rate
BTT	Total heat release
Btu/ft^2	British Thermal Units per square foot
$Btu/ft^2/min$	British Thermal Units per square foot per minute
$Btu/ft^2/sec$	British Termal Units per square foot per second
Btu/lb	British Thermal Units per pound
C	LOI of core
°C	Degrees Celsius
C_K	A constant
C_T	Core thickness
Calif	California
°C/min	Degrees Celsius per minute
cm	Centimeter
cm^2	Square centimeter
cm-Hg	Centimeters of mercury
cm·kg	Centimeter kilogram
cm/min	Centimeters per minute
cm^3/min	Cubic centimeters per minute
cm^3/sec	Cubic centimeters per second
CO	Carbon monoxide
CO_2	Carbon dioxide

Corr	Corrected
COU	CO concentration at 1.0 W/cm^2 (52.9 Btu/ft^2/min) and 4.0 minutes
COX	CO concentration at 2.5 W/cm^2 (132.2 Btu/ft^2/min) and 4.0 minutes
COZ	CO concentration at 5.0 W/cm^2 (264.3 Btu/ft^2/min) and 4.0 minutes
CR	Contract report
d	Distance
D_M	Maximum specific optical density
D_S	Specific optical density
DA	Total heat release of adhesive
DB	Total heat release of bond ply
DC	Total heat release of core
DD	Panel density
$d(D_M)/dt$	Derivative of D_M with respect to time
$d(D_S)/dt$	Derivative of D_S with respect to time
DF	Total heat release of foam
DFS	Total heat release of face sheet
dQ/dt	Derivative of heat release with respect to time
DT	Panel thickness
DTA	Differential thermal analysis
e.g.	For example
etc.	And so forth
F	LOI of foam
^oF	Degrees Fahrenheit
F_o	Load
F_1	Load
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
fig.	Figure
^oF/min	Degrees Fahrenheit per minute
FM-PVF	Flame modified polyvinyl fluoride
FS	LOI of face sheet
FS&T	Flammability, smoke, and toxicity
ft	Foot
ft^2	Square foot
ft^3	Cubic foot
\$/ft^2	Dollars per square foot
ft/min	Feet per minute
ft^3/min	Cubic feet per minute
FTMS	Federal Test Method Standard
FTS	Flatwise tensile strength
gm	Gram
gr/oz	Grains per ounce
h	Total sandwich panel thickness
HCl	Hydrogen chloride
HCN	Hydrogen cyanide
HCNU	HCN concentration at 1.0 W/cm^2 (52.9 Btu/ft^2/min) and 4.0 minutes
HCNX	HCN concentration at 2.5 W/cm^2 (132.2 Btu/ft^2/min) and 4.0 minutes
HCNZ	HCN concentration at 5.0 W/cm^2 (264.3 Btu/ft^2/min) and 4.0 minutes

HF	Hydrogen fluoride
hr	Hour
HRU	Maximum heat release rate at 1.0 W/cm^2 (52.9 Btu/ft^2/min)
HRX	Maximum heat release rate at 2.5 W/cm^2 (132.2 Btu/ft^2/min)
HRZ	Maximum heat release rate at 5.0 W/cm^2 (264.3 Btu/ft^2/min)
HSRU	d(D_M)/dt at 1.0 W/cm^2 (52.9 Btu/ft^2/min)
HSRX	d(D_M)/dt at 2.5 W/cm^2 (132.2 Btu/ft^2/min)
HSRZ	d(D_M)/dt at 5.0 W/cm^2 (264.3 Btu/ft^2/min)
HSTU	D_M at 1.0 W/cm^2 (52.9 Btu/ft^2/min)
HSTX	D_M at 2.5 W/cm^2 (132.2 Btu/ft^2/min)
HSTZ	D_M at 5.0 W/cm^2 (264.3 Btu/ft^2/min)
HTU	Total heat release at 1.0 W/cm^2 (52.9 Btu/ft^2/min)
HTX	Total heat release at 2.5 W/cm^2 (132.2 Btu/ft^2/min)
HTZ	Total heat release at 5.0 W/cm^2 (264.3 Btu/ft^2/min)
i	Number of terms in the numerator
ICU	Isocyanurate
i.e.	That is
ign	ignition
in.	Inch
in.^{2}	Square inch
in.^{3}	Cubic inch
inc	Incorporated
in./ft	Inches per foot
in.-Hg	Inches of mercury
in.-lb	Inch pound
in./min	Inches per minute
IS	Impact strength
J/cm^2	Joules per square centimeter
J/gm	Joules per gram
K	Percent transmission
K.C.	Kansas City
kg	kilogram
kg/cm	Kilograms per centimeter
kg/cm^2	Kilograms per square centimeter
kg/m^2	Kilograms per square meter
kg/m^3	Kilograms per cubic meter
kW/m^2	Kilowatts per square meter
L	Length
lb	Pound
lb/ft	Pounds per foot
lb/ft^2	Pounds per square foot
lb/ft^3	Pounds per cubic foot
lb/in.	Pounds per inch
lb/in.^{2}	Pounds per square inch
LH	Manhours of labor
$\log_{10}$	Logarithm to the base 10
LOI	Limiting Oxygen Index
M	Modulus

m	Meter
m^2	Square meter
m^3	Cubic meter
max	Maximum
MC	Material cost
MEK	Methyl ethyl ketone
mg	Milligram
mg/gm	Milligrams per gram
min	Minute
min^{-1}	Reciprocal minute
misc	Miscellaneous
mm	Millimeter
MMC	Miscellaneous material cost
mm/cm	Millimeters per centimeter
m/min	Meters per minute
m^3/min	Cubic meters per minute
mm/min	Millimeters per minute
Mo	Missouri
mod	Modification
N_2	Nitrogen
NaOH	Sodium hydroxide
NASA	National Aeronautics and Space Administration
NASA-ARC	National Aeronautics and Space Administration-Ames Research Center
NASA-JSC	National Aeronautics and Space Administration-Johnson Space Center
NBS	National Bureau of Standards
N/m^2	Newtons per square meter
no.	Number
NO_X	Oxides of nitrogen
no./cm	Number per centimeter
no./in.	Number per inch
NPRM	Notice of Proposed Rule Making
NW	Northwest
O_2	Oxygen
OSU	Ohio State University
oz	Ounce
oz/yd^2	Ounces per square yard
oz/yd^3	Ounces per cubic yard
P	Load
PB	Peel strength of back skin
PC	Polycarbonate
PCF	Pounds per cubic foot
PES	Polyethersulfone
PF	Peel strength of face skin
PI	Polyimide
P.O.	Post Office
pp	Pages
ppm	Parts per million

PQ	Polyquinoxaline
psi	Pounds per square inch
PU	Polyurethane
PVA	Polyvinyl-alcohol
PVC	Polyvinyl chloride
PVF	Polyvinyl fluoride
PVF_2	Polyvinylidene fluoride
P/Y	Slope of initial portion of load-deflection curve
Q	Heat release
QPL	Qualified products list
R_o	Flange radius
R_I	Drum radius
ref.	Reference
RT	Room temperature
S	South
S_c	Compressive stress
S_p	Peel strength
sec	Second
sec^{-1}	Reciprocal second
S_{NUU}	D_S at 1.0 W/cm^2 (52.9 Btu/ft^2/min) and 1.5 minutes
S_{NUX}	D_S at 1.0 W/cm^2 (52.9 Btu/ft^2/min) and 4.0 minutes
S_{NUZ}	Maximum D_S at 1.0 W/cm^2 (52.9 Btu/ft^2/min)
S_{NXU}	D_S at 2.5 W/cm^2 (132.2 Btu/ft^2/min) and 1.5 minutes
S_{NXX}	D_S at 2.5 W/cm^2 (132.2 Btu/ft^2/min) and 4.0 minutes
S_{NXZ}	Maximum D_S at 2.5 W/cm^2 (132.2 Btu/ft^2/min)
S_{NZU}	D_S at 5.0 W/cm^2 (264.3 Btu/ft^2/min) and 1.5 minutes
S_{NZX}	D_S at 5.0 W/cm^2 (264.3 Btu/ft^2/min) and 4.0 minutes
S_{NZZ}	Maximum D_S at 5.0 W/cm^2 (264.3 Btu/ft^2/min)
SO_2	Sulfur dioxide
STAR	Scientific and Technical Aerospace Reports
syst	System
T	Percent transmission
t	Time
T_o	Outlet temperature
T_I	Inlet temperature
t_c	Compression face thickness
t_t	Tensile face thickness
TGA	Thermogravimetric analysis
UV	Ultraviolet
V	Volume
V_{f1}	Volumetric flow rate of O_2
V_{f2}	Volumetric flow rate of N_2
viz	Namely
vol	Volume
VRU	Maximum heat release rate at 1.0 W/cm^2 (52.9 Btu/ft^2/min)
VRX	Maximum heat release rate at 2.5 W/cm^2 (132.2 Btu/ft^2/min)
VRZ	Maximum heat release rate at 5.0 W/cm^2 (264.3 Btu/ft^2/min)
VSRU	$d(D_M)/dt$ at 1.0 W/cm^2 (52.9 Btu/ft^2/min)

VSRX	$d(D_M)/dt$ at 2.5 W/cm^2 (132.2 $Btu/ft^2/min$)
VSRZ	$d(D_M)/dt$ at 5.0 W/cm^2 (264.3 $Btu/ft^2/min$)
VSTU	D_M at 1.0 W/cm^2 (52.9 $Btu/ft^2/min$)
VSTX	D_M at 2.5 W/cm^2 (132.2 $Btu/ft^2/min$)
VSTZ	D_M at 5.0 W/cm^2 (264.3 $Btu/ft^2/min$)
VTU	Total heat release at 1.0 W/cm^2 (52.9 $Btu/ft^2/min$)
VTX	Total heat release at 2.5 W/cm^2 (132.2 $Btu/ft^2/min$)
VTZ	Total heat release at 5.0 W/cm^2 (264.3 $Btu/ft^2/min$)
w	Width
WA	Weight of devolatilized specimen before burnout
W/cm^2	Watts per square centimeter
WM	Weight of constituents prior to test
WN	Weight of constituents after test
$W \cdot sec/cm^2$	Watt seconds per square centimeter
XHCN	HCN concentration at 2.5 W/cm^2 (132.2 $Btu/ft^2/min$) and 10.0 minutes
yd	Yard
σ	Standard deviation
&	And
*	Asterisk
@	At
÷	Divided by
$	Dollar
-	Minus
#	Number
%	Percent
+	Plus
±	Plus or minus
x	Times or by

4.0 TEST PROGRAM

The Test Program section has been divided into two separate sections:

1. Test Methods

2. Test Materials

4.1 TEST METHODS

A broad range of flammability, thermophysical, and mechanical tests was run to fully characterize the candidate materials and to select the appropriate test methods to be used in future programs. The extensive laboratory testing in the flammability area was necessary because the implications of laboratory-scale test results are not fully understood. That is, correlation between small-scale and large-scale tests has not been established.

4.1.1 FLAMMABILITY TESTS

It was desirable to measure five basic properties of the materials. (1) propensity to burn, (2) smoke emission, (3) toxic gas emission and toxicological properties, (4) heat release, and (5) flame penetration. In some cases, more than one test apparatus was used to measure the same property, thus giving a comparison of test methods. Also, a range of incident heat fluxes was used to determine the material response to various fire conditions. The complete flammability test matrix is shown in table 1.

Propensity to Burn

The propensity to burn was measured using the standard Bunsen burner exposure test and the Limiting Oxygen Index test.

The vertical 60-second ignition Bunsen burner test was chosen because it is the standard flammability test required by the FAA for wide cabin interior materials (ref. 14). This test measures the time to extinguishment and burn length after the igniting flame is removed. The procedure is described in appendix A (sec. A.1) and a typical test setup is shown in figures 2 and 3.

The Limiting Oxygen Index (LOI) test was run to determine the propensity of the materials to burn. This test exposes the specimen to an open flame in a controlled nitrogen/oxygen atmosphere. The ratio of N_2/O_2 is regulated; thus, concentrations up to 100% O_2 can be obtained (ref. 15). A higher amount of O_2 necessary to sustain burning would indicate a greater resistance to burning and an index rating of 100 would indicate that the material would only burn in an atmosphere of 100% O_2. The LOI gives a ranking index that may be used to compare materials. The procedure is described in appendix A (sec. A.2) and figures 4 and 5 show the apparatus and test setup.

Smoke Emission

The smoke emission characteristics of the candidate materials were determined using two techniques—smoke accumulation in an enclosure was measured using the NBS smoke chamber and smoke emission in an exposed air stream was measured using the Ohio State University Release Rate apparatus. Both apparatuses were operated over a range of incident heat fluxes, 1.0 to 5.0 W/cm^2 (52.9 to 264.3 $Btu/ft^2/min$), to determine the responses of materials to various fire environments..

The NBS chamber was selected in the FAA's proposed smoke regulation (ref. 1) because it is a laboratory simulation thought to represent a cabin fire. The chamber is sealed during the test; thus, oxygen depletion takes place and smoke builds up during the exposure. Specimens are exposed to a radiant heat source and pilot flame. The smoke obscuration is measured by passing a light beam through the cabinet and measuring light transmission loss. The procedure is described in appendix A (sec. A.3) and figures 6 and 7 show the apparatus.

The OSU Release Rate apparatus exposes specimens to a radiant heat source in a chamber through which air is ducted. Smoke emission is measured by recording the light transmission across the exhaust stack. The procedure is described in appendix A (sec. A.4) and figures 8 and 9 show the apparatus.

Toxic Gas Emission

Toxic gas emissions were measured in two separate tests: the gas accumulation in the NBS chamber and a quantitative measure of gases from pyrolysis tube decomposition. The NBS chamber exposure represents an open fire condition where only partial (or surface) burning takes place. The pyrolysis tube exposure represents complete decomposition of the sample as the specimen is exposed to a 600°C (1112°F) heat source.

Samples were taken in the NBS chamber by using colorimetric tubes (for SO_2, HCN, and NO_X), NaOH absorber solutions (for halide gases), and on-line gas detectors (for CO, CO_2, and O_2). The NaOH solutions were analyzed using specific ion electrode. Samples were taken of the pyrolysis tube effluent using NaOH absorber solutions. The difference between the two sample techniques was that the gases from the NBS chamber were taken as a grab sample and results were expressed as a concentration (ppm) of the gas in the accumulation chamber, while gases from the pyrolysis tube were absorbed during the entire test and results were expressed as a total yield (i.e., mg of gas per gram of sample).

The NBS chamber procedure is described in appendix A (sec. A.3) and figures 6 and 7 show the apparatus. The pyrolysis tube decomposition procedure is also described in appendix A (sec. A.5).

Toxicological Properties

Relative toxicity was determined utilizing the NASA Animal Exposure Chamber. The procedure is described in appendix A (sec. A.6) and figure 10 shows the apparatus.

Heat Release

Heat release was measured using the OSU Release Rate apparatus. As with the smoke release tests, the apparatus was operated over a range of heat fluxes to determine the material responses to various fire threats. The procedure is described in appendix A (sec. A.4) and figures 8 and 9 show the apparatus.

Flame Penetration

The flame penetration properties were measured on the Boeing Burn Through apparatus. This device measures the resistance of the panel to an open flame condition, 8-9 W/cm^2 (422.9-475.8 Btu/ft^2min). Also, an estimate of the heat release rate and total heat released can be made by measuring the stack gas temperature change just as it is done in the OSU apparatus. The procedure is described in appendix A (sec. A.7) and figures 11-15 show the apparatus.

4.1.2 THERMOPHYSICAL TESTS

Both Differential Thermal Analysis (DTA) and Thermogravimetric Analysis (TGA) tests were run to determine the decomposition rates of the materials. These tests were used to determine the exothermic (or endothermic) rate of the material as they were decomposing, as well as their weight loss. The materials with high exothermic rates were considered undesirable because of their contribution to a fire scenario. Materials with a high weight loss at temperatures below 260°C (500°F) were undesirable because the gases given off at these low temperatures would contribute ignitable fuel to a fire. Note that water would be an exception; thus, weight losses that occurred at 99-104°C (210-220°F) were ignored. The thermophysical test matrix is shown in table 2 and the DTA/TGA test procedures are described in appendix A (sec. A.8).

4.1.3 MECHANICAL TESTS

The mechanical strength requirements are relatively minimal and the most severe conditions are shop handling and installation loads. The primary criteria are adhesive strength to the honeycomb core and resistance to impact. Peel strength and flatwise tension tests were selected to measure the bond strength of the resin systems. The impact resistance was measured using a Gardener impact test. The mechanical test matrix is shown in table 3 and the detailed test procedures are described in appendix A in the following sections:

Peel Strength	Sections A.9 and A.10
Flexure	Section A.11
Flatwise Tension	Section A.12
Fabric Wear	Section A.13
Taber Abrasion	Section A.14
Elongation	Section A.15
Impact Strength	Section A.16

4.1.4 ADDITIONAL TESTS

Tests were run on the decorative films to determine their resistance to staining, their resistance to UV light, and their decorative capability. Also, densities were determined for the candidate sandwich panels. Stain resistance was measured by placing small amounts of contaminants (e.g., butter, mayonnaise, chocolate, etc.) on a specimen and allowing them to dry, and washing the specimen with standard alkaline cleaners. Color stability was measured by monitoring color shifts in the decorative facing under two different conditions: (1) as the specimen was cured and (2) after exposure of the specimen to UV light. The additional test matrix is shown in table 4 and the detailed test procedures are described in appendix A in the following sections:

Density	Section A.17
Stain Resistance	Section A.18
Ultraviolet Stability	Section A.19
Decorative Capability	Section A.20

4.2 TEST MATERIALS

New materials were selected to determine their reduction in fire hazard through burning more slowly, emitting less smoke, emitting less toxic gas, or emitting less heat during a fire exposure. The face sheet resins that were tested included modified phenolics, bismaleimides, and polyimides. These resin systems were impregnated into fiberglass cloth and were compared to the baseline epoxy/fiberglass system. The sandwich core systems studied included the baseline phenolic/polyamide and alternative core materials made of polyimide/polyamide and polyimide/fiberglass. Also, honeycomb filled with foam was investigated as a means of decreasing the thermal conductivity of the panel (i.e., increasing the thermal resistance as well as providing an ablation shield for high heat flux conditions). The decorative film systems studied were modified polyvinyl fluoride, polyvinylidene fluoride, polycarbonate, and polyethersulfone. These films were compared to the baseline polyvinyl fluoride used by aircraft manufacturers today.

During the screening tests, materials of similar fire hardness were combined to produce a candidate sandwich panel. That is, phenolic skins were used with phenolic core and polyimide skins were used with polyimide core. A complete matrix of candidate material systems appears in tables 5-8 and is illustrated in figures 16-20 along with the baseline epoxy system.

4.2.1 BASELINE SYSTEM

Two basic types of decorative sandwich panels are currently in use by aircraft companies, as shown in figure 21. The first system consists of a precured blank panel onto which is bonded a decorative polyvinyl chloride outer layer. The materials used in the sandwich skins are normally flame-retarded epoxy/fiberglass (e.g., halogenated). The honeycomb core, prior to 1970, was phenolic/kraft paper which has subsequently been changed to phenolic/polyamide paper. The second type of decorative sandwich consists of an integral decorative skin that replaces the polyvinyl chloride as well as forming the structural member of the sandwich panel. The decorative layer in this type of construction is printed or silkscreened

polyvinyl fluoride. The face sheets are flame-retarded epoxy/fiberglass and the honeycomb core is phenolic/polyamide. It was this second type of panel that was modified and tested in this program.

4.2.2 TEST SYSTEMS – FACESHEET RESINS

Three types of resins were considered: Phenolic, bismaleimide, and polyimide. Each of these resins offers generic fire resistance without the need for fire-retardant additives that could add toxic species to the resin. All resins were impregnated into standard glass fabrics.

The phenolics were experimental prepreg systems and are listed following.

Manufacturer	Facesheet Prepreg	Adhesive Prepreg
Narmco	8250	9250
Narmco	8250	9251
Narmco	8250	8250
Fiberite	MXB-6070	MXB-7255
Fiberite	MXB-6070	MXB-6070
Ciba-Geigy	Fibredux 917G	Fibredux 917G
Ciba-Geigy	Fibredux 428	Fibredux 428
Dupont	Corlar 6113-1	Corlar 6113-1

These systems are modified phenolics that were formulated to cure at 160°C (320°F) for the facesheet and 121°C (250°F) for the adhesive. Various combinations of adhesive and facesheet plies could be used to fabricate nonstructural panel blanks or nonstructural decorative panels.

Two types of bismaleimides were tested – the 177°C (350°F) curing Rhodia Kerimid 601 and the 121°C (250°F) curing Hexcel 531/Hexcel 532 system. The Kerimid 601 system required FM-34 adhesive to bond the facesheets to the honeycomb core. The Hexcel 532 is an adhesive prepreg and can be used to bond precured facesheets or cocure with facesheets. For this program Hexcel 532 was used to bond precured facesheets to the core. The Kerimid 601 system was developed by Hitco Corporation under a NASA contract (ref. 16).

A single polyimide resin system was tested – Dupont Pyralin 3002. This system required BR-34 adhesive to bond the facesheets to the honeycomb core.

4.2.3 TEST SYSTEMS – CORE MATERIALS

Two basic concepts were tested – standard honeycomb and honeycomb that had been filled with foam. Phenolic/polyamide was used in the baseline epoxy sandwiches and, because of its inherent fire stability, was chosen as the standard for these tests. Alternative types of core that were tested were: polyimide/polyamide and polyimide/fiberglass.

Foam-filled honeycomb was tested because foam could reduce the thermal conductivity and flame penetration. Four were chosen that offered generic fire resistance:

1. Polyquinoxaline (PQ)

2. Isocyanurate (ICU) -- standard and pyrolyzed

3. Phenolic

4. Polyimide/polyurethane

4.2.4 TEST SYSTEMS–DECORATIVE FILMS

Film materials were selected on the basis of minimizing the amount of toxic gas emission and the surface flammability of the material. Candidate films included:

Polyvinyl fluoride-Tedlar-PVF

Flame-modified polyvinyl fluoride-FM Tedlar–PVF

Polyvinylidene fluoride-Fluorex H-PVF_2

Polycarbonate-PC

Polyethersulfone-PES

See figure 20 for a complete description.

5.0 RESULTS AND DISCUSSION

As discussed earlier, this was a multi-task laboratory test program. Discussion of the results will be segmented into the five different tasks as shown in figure 22.

5.1 TASK 1

Preliminary screening tests were conducted to examine viable phenolic systems. Tables 9-14 contain the data obtained during Task 1 testing. It was found that the phenolic resins tested produced less smoke than the epoxy system (see table 9); however, the phenolics exhibit unacceptable mechanical properties, particularly in the area of peel strength (see tables 10 and 11). It was also found that the HF emission varied significantly even though the same amount of PVF was used on each panel (see tables 12 and 13). This variation is most likely due to the differences in absorption of the phenolic char and soot as the panels were being tested. In later testing, decorative layers were tested as isolated components to determine the potential gas emissions of the fiber material (see Task 3 results).

Based on the test results, the candidate systems were considered unacceptable for further testing. As a result, a new set of material systems was utilized for subsequent evaluation in this program.

5.2 TASK 2

Based on the screening tests run in Task 1, it was concluded that extensive flammability, thermophysical, and mechanical tests were needed in Task 2. To fully characterize the candidate systems, tests at higher heat fluxes and more flammability data were needed (viz., heat release rates, oxygen index, toxic gas release rates, and resistance to flame penetration). Tables 1-4 give the complete test matrix. Revised phenolic systems were chosen from Task 1 and supplemented with bismaleimide and polyimide resin systems (see table 6). Sandwich panels were tested with and without foam-filled honeycomb core to determine the advantages of an added thermal barrier. The tests are discussed individually in the following paragraphs.

5.2.1 LIMITING OXYGEN INDEX (LOI)

Individual components of the sandwich panels were tested independently (viz., face sheets, adhesive plies, adhesives, honeycomb cores, and foams). Figures 23-25 are graphical representations of the data contained in table 15. In all cases, the resin and reinforcement were tested as a heterogeneous specimen.

The LOI for the bond ply was, in all cases, lower than for the face sheet. This indicates that the resin additives, increased resin content, or thinner material, of the bond ply tended to increase its propensity to burn.

The epoxy baseline system had LOI's of 29.0, 27.7, and 30.9 for the skin, bond ply, and honeycomb core, respectively. These low values indicate that the epoxy resin, as well as the

phenolic/polyamide core, have about an equal propensity to burn. The phenolic systems ranged from 23.0 to 53.5 for the bond plies and 50.7 to 100 for the skin plies, indicating a wide range of fire resistance for the various phenolics and an even greater difference between the bond ply and skin ply formulations. The bismaleimides ranged from 24.6 to 52.6 for the bond plies and 33.9 to 56.0 for the face sheets. These differences indicate a greater fire resistance for the 177°C (350°F) curing BMI's. The polyimides exhibited LOI values of 100 and 49.8 for the face skin and adhesive, respectively. It is pointed out that the thinner 120 style polyimide prepreg had an LOI of 71.4, while the thicker 181 style polyimide prepreg had one of 100. The fact that the same resin system exhibited two different LOI's is attributed to the difference in resin content and/or thickness of the prepregs.

While these LOI data are not conclusions in themselves, they do indicate a general ranking of the systems. This ranking, combined with other flammability properties, can give an overall ranking of the systems, but the deficiencies of the LOI test must be considered (e.g., thickness effect, etc.).

5.2.2 SMOKE EMISSION

The smoke emission of the systems was measured in two test apparatuses: the NBS smoke chamber, which is a closed, noncirculating accumulation chamber, and the Ohio State Release Rate apparatus, which is closed but has a controlled amount of air that is ducted over the surface of the specimen. Both apparatuses were operated over a range of heat fluxes to fully characterize the response of the materials. Figures 26-31 are graphical representations of the data contained in tables 16-18.

In general, the smoke release rate and specific optical density increased for both apparatuses as the heat flux was increased. This increase is due to more material becoming involved in the combustion at higher heat fluxes. In most cases, the smoke release for the epoxy system was the greatest, followed in order by low-temperature bismaleimides, high-temperature bismaleimides, phenolics, and polyimides.

In all cases, the addition of foam to the honeycomb increased the amount of smoke released. This additional release is to be expected since the foam adds more fuel to the sandwich panel (i.e., more mass is available for combustion). The foam added to the polyimide systems was a copolymer of urethane and polyimide, and during test contributed a large amount of smoke.

5.2.3 HEAT RELEASE

The amount and rate of heat release were measured using the OSU Release Rate apparatus run at heat fluxes of 1.0 to 5.0 W/cm^2 (52.9 to 264.3 Btu/ft^2/min) with specimens mounted in a horizontal as well as vertical mode. Figures 32-35 are graphical representations of the data contained in tables 19 and 20.

Figures 36-41 contain photographs of some of the specimens following testing. In general, the figures show that as the heat flux increases the face sheets change color toward white, indicating a loss of resin. This coincides with the data, which show an increase in heat release with increasing heat flux (i.e., more resin consumed means more heat release).

In general, the total heat released and maximum rate of heat release for all the systems increased as the incident heat flux was raised from 1.0 to 5.0 W/cm^2 (52.9 to 264.3 Btu/ft^2/min). Note that both System 4 and System 10 exhibit a decrease in heat release from 2.5 W/cm^2 (132.2 Btu/ft^2/min) to 5.0 W/cm^2 (264.3 Btu/ft^2/min). This phenomenon is most likely due to the heat sink provided by the specimen holder. The specimen holder provides a large enough heat sink variation from one test to the next that, for low heat output materials, an apparent anomaly may result.

It can be seen from the data that the higher heat fluxes resulted in greater differences between the systems with respect to their heat release characteristics. For example, note the differences between System 2 and System 10, both of which contain a phenolic resin. Such disparities as this are due to the differences in chemical structure, char formation, and amount of resin consumed.

Heat release must be considered as one of the most important flammability properties. Heat release characteristics of a material can give a relative measure of its contribution towards both raising the cabin air temperature and providing a high heat flux for ignition of additional materials.

5.2.4 FLAME PENETRATION

The flame penetration provides another means of measuring heat release. As described in appendix A (sec. A.7), the flame penetration test exposes the specimen to an open flame, high heat flux condition; i.e., 8-9 W/cm^2 (422.9-475.8 Btu/ft^2/min). Figures 42-44 are graphical representations of the data contained in tables 21 and 22. In addition to the data presented, photographs of typical test specimens were made and are presented in figure 45.

Under exposure to the conditions of this test, the phenolic and polyimide systems (Systems 2, 4, 8, 10, and 12) release about half as much heat as the baseline epoxy. The bismaleimides (Systems 7 and 13) released about the same heat as the epoxy with the exception of the low-temperature-curing System 3. In general, the maximum heat release rate of the phenolics and polyimides was less than that of the epoxy baseline. The maximum rate was greater than the epoxy in the case of the bismaleimides.

Addition of foam to the honeycomb core decreased the heat transmitted through the panel, as illustrated in figure 44. However, the foam provided additional fuel and more heat was released as a result of its presence (see figure 42).

5.2.5 TOXICITY CHARACTERISTICS

Toxic gas evolution was measured by sampling the gases as collected in the NBS smoke chamber during the smoke emission test, while the relative toxicity of the gases evolved during pyrolysis was determined utilizing the NASA Animal Exposure Chamber. Figures 46-48 are graphical representations of the data contained in tables 23 and 24.

The NBS chamber gas samples showed relatively small amounts of HCN and CO given off during the tests (see figs. 46 and 47). Results from the NASA Animal Exposure Chamber

test indicate the toxicity of the resin systems tested to be about the same (see fig. 48). However, the epoxy resin appears to be slightly more toxic based on this test.

5.2.6 THERMOPHYSICAL CHARACTERISTICS -

Thermogravimetric Analysis (TGA) and Differential Thermal Analysis (DTA) tests were run on individual components of the sandwich panels (viz., face sheet, bond ply, adhesives, core, and foam). Cured laminates (face sheets and bond plies) and cured adhesives were tested as they would exist in actual use to determine the temperature at which thermal degradation occurred. Figures 49-56 are graphical representations of the data contained in tables 25-30.

The TGA results were not useful because they could not be applied as a screening tool to select the thermally stable materials. For example, those materials that had lower breakdown temperatures had no relation to LOI, as shown in figure 57. Likewise, DTA results were not useful because they could not be applied as a screening tool to select materials possessing low heat evolution during pyrolysis conditions. For example, no correlation was found between the heat release measured in the Mettler Thermoanalyzer and that measured in the OSU Release Rate apparatus (see fig. 58). Note that the DTA heat release values plotted in figure 58 were calculated by the following formula:

DTA Heat Release = 1/2 (DTA-Face Sheet) + 1/3 (DTA-Bond Ply) + 1/6 (DTA-Core)

where:

DTA Heat Release	=	value plotted
DTA-Face Sheet	=	value from table 30
DTA-Bond Ply	=	value from table 30
DTA-Core	=	value from table 30

5.2.7 MECHANICAL PROPERTIES

Peel strength, flatwise tensile strength, and impact strength tests were run on each of the sandwich panels. Figures 59-61 are graphical representations of the data contained in tables 31-33.

The primary interest for interior panel strengths is with the bond strengths of the honeycomb sandwich. Emphasis is placed on peel and flatwise tension rather than face sheet load-carrying capability. This emphasis on honeycomb bond strengths is necessary to ensure that the panels will withstand the rigors of shop handling and installation without delamination. Goals of 11.5 cm-kg/7.62cm width (10.0 in.-lb/3 in. width) peel strength and 10.5 kg/cm^2 (150.0 $lb/in.^2$) flatwise tensile strength were set for the program (see figs. 59 and 60). No relationship was found between systems that had low bond strengths and those that had low flammability properties. Such a relationship might exist for a given resin system and should be considered if formulation changes are proposed as a means of increasing the honeycomb bond strength.

Figure 61 shows the results of the Gardener impact strength tests. Bismaleimide systems possessed the greatest strength, followed in order by the baseline epoxy, modified phenolics,

and polyimides. Conclusions based on the relative comparison between the resin systems noted is rather difficult due to the variation in resin content, number of plies of prepreg, and type of glass reinforcement used. For example, the low-temperature-cured bismaleimide system contained a large amount of resin and all of the polyimide systems contained only one ply of type 181 glass fabric prepreg with no bond ply.

5.2.8 ADDITIONAL PROPERTIES

One additional parameter was measured that determined the relative weights of the 13 sandwich panels (viz., density). Figure 62 is a graphical representation of data contained in table 34. Two of the phenolics (Systems 10 and 12) were less dense than the baseline epoxy. The foam-filled polyimides were the heaviest, followed in order by high-temperature-cured bismaleimides, low-temperature-cured bismaliemides, and the remaining polyimides and phenolics.

5.3 TASK 3

The most critical flammability tests were considered to be LOI and smoke and toxic gas output, since these properties would determine the propensity to burn, smoke emission characteristics, and products of combustion of the films. The critical mechanical strength of the film systems was adhesion of substrate film to top film and to substrate sandwich panels. The materials matrix is shown in table 7. The tests will be discussed individually.

5.3.1 LIMITING OXYGEN INDEX (LOI)

As with the sandwich panel constituents, propensity to burn was measured using the limiting oxygen index procedure. Individual layers of film, as well as film composites, were tested. The film composites contained the decorative acrylic ink currently used in production. Figure 63 is a graphical representation of the data contained in table 35.

As shown in figure 63, the addition of acrylic ink increases the propensity to burn, e.g., 0.025 mm (0.001 in.) PVF (LOI = 46.0) combined with 0.025 mm (0.001 in.) FM-PVF (LOI = 67.8) and acrylic ink yielded a composite with an LOI of 28.9. The data also show that the film composite of 0.025 mm (0.001 in.) clear PVF and 0.127 mm (0.005 in.) white PC (Film No. 4) has the least propensity to burn of all the composites tested. Film No. 3 is second best, followed in order by Film Nos. 2, 5, and 1.

5.3.2 SMOKE EMISSION

The smoke emission characteristics of the films were measured in the NBS smoke chamber, which is a closed, noncirculating accumulation chamber. A range of heat fluxes was investigated to fully characterize the response of the films. Figures 64 and 65 are graphical representations of the data contained in table 36.

In general, the specific optical density increased as the heat flux was increased. This increase is due to more material becoming involved in the combustion at higher heat fluxes. The smoke release for polycarbonate (Film No. 4) was the greatest, followed in

order by Tedlar (Film No. 1), FM-Tedlar (Film No.2), polyethersulfone (Film No. 5), and Fluorex H (Film No. 3).

5.3.3 FLAMMABILITY

The flammability of the films was determined by performing the 60-second vertical FAA flammability test. All five films met and exceeded the requirements of FAR 25-32. Table 37 is a tabulation of the test results obtained.

5.3.4 TOXICITY CHARACTERISTICS

Three separate toxicity tests were performed on the films: (1) gas analysis of specimens exposed in the NBS chamber, (2) gas analysis of pyrolyzed samples, and (3) NASA Animal Exposure Chamber. There were differences in the amount of gases evolved in tests (1) and (2), indicating that test methodology had an influence on the amount of gas detected (i.e., some HF gas is absorbed by the test equipment because of its extreme reactivity).

The NBS chamber gas analyses were run over a range of incident heat fluxes to characterize the behavior of the films at different fire exposures. It was found that higher heat fluxes produced greater amounts of HF gas. See figure 66 and table 38.

Gas anaysis of the pyrolyzed samples was run utilizing a quartz glass pyrolysis tube and repeated using a Monel tube. It was found that the Monel tube absorbed less HF; hence, more HF gas was detected in Monel tube tests. See figure 67 and table 39.

The NASA Animal Exposure Chamber test was run to determine toxicological characteristics of the effluent pyrolysis gases on animals. See figure 68 and table 40 for test results.

The relative ranking of the films was roughly the same for the NBS chamber and pyrolysis tube gas analysis methods, as shown in table 41. However, the animal exposure test data show FM-PVF (Film No. 2) to be the least toxic and PVF/PC (Film No. 4) to be nearly the most toxic, which would appear to contradict the gas analysis results.

5.3.5 MECHANICAL PROPERTIES

Mechanical strengths of the decorative films were determined with elongation tests and peel tests.

Elongation tests were run to check the ability of the films to be textured and formed to complex shapes. In addition, elongation tests were run on composite films to determine if lamination to adhesives or acrylic inks would degrade the ability of the films to conform to textured or contoured parts. Although no precise elongation requirement can be established, it is desirable to have a minimum of 20-30%. To achieve this objective, it is advantageous to use components that have the necessary elongation and also to use adhesives and ink that will not sensitize the film. As seen in figure 69 and table 42, Film No.1 components, as well as the composite itself, have relatively good elongations. The polycarbonate system (Film No. 4) components had adequate elongations when measured separately; however,

when combined with adhesives and ink to form a composite, the polycarbonate was embrittled and only a 5.0% elongation was achieved.

Peel tests were run to determine the adequacy of the adhesion between the top and substrate films. While no definite requirement has been established, this test does give an indication of a film's capability to adhere to the substrate. No peel strengths could be obtained on the films since, in every case, the top film broke prior to any peel occurring. This indicates that the bond strength of each composite exceeded the strength of the top film.

5.3.6 ADDITIONAL PROPERTIES

Two additional tests were performed on the decorative films in Task 3: (1) stain resistance and (2) ultraviolet stability. The purpose of these tests was to determine some of the serviceability characteristics of the films.

The stain resistance test is designed to determine the cleanability of a surface that has been exposed to various soiling materials. These materials are items commonly found on board a commercial aircraft (viz., butter, mayonnaise, chocolate, soup, and orange juice). No discoloration of any of the five films was noted after 24 hours of exposure to the soiling materials.

The ultraviolet stability test allows the determination of long-term effects on a material resulting from exposure to ultraviolet light. No deleterious effects on any of the five films were detected even after 295 hours of exposure to UV radiation. See table 43.

5.4 TASK 4

The PVF/PC (Film No. 4) film combination was selected for further testing because, during the Task 3 evaluation, it (1) exhibited the least propensity to burn and (2) evolved the least amount of toxic gases as measured in the NBS smoke chamber at 2.5 W/cm^2 (132.2 Btu/-ft^2/min). PVF/PC film was compared with the baseline PVF/PVF film composite. Tests were conducted with five of the panel face sheet skins (see table 8) to determine compatibility, durability, and aesthetic qualities.

It was determined that PVF/PC formed an unacceptable bond with the face sheet skins; therefore, an acrylic adhesive (DuPont 6880) was employed between the film and the prepreg. The epoxy and phenolic resin systems were cocured with the decorative films, while the polyimide resin system was secondarily bonded using a polyester adhesive (TF-252). Each of the resin/film combinations was textured by means of a piece of canvas cloth.

5.4.1 MECHANICAL PROPERTIES

Peel tests and abrasion tests were run to determine the adhesion and wear characteristics of the decorative films. Peel test results are tabulated in table 44 and graphically illustrated in figure 70. Tables 45 and 46 and figure 71 show the results of the wear tests.

The peel test results show the bond strength to be greater than the film composite in all cases. It is, however, noted that the breaking strength of the PVF/PC film was less than the PVF/PVF film except in the case of Ciba-Geigy Fibredux 917G face skin (Systems A-2 and B-2).

Based on weight loss, the Taber abrasion test showed the baseline PVF/PVF to be more susceptible to wear than the PVF/PC film. From a durability standpoint (cycles to failure), PVF/PC exhibits total failure sooner than the baseline PVF/PVF. This is most likely due to the difficulty in determining failure of the white background ink in the case of the 0.051 -mm (0.002-in.) white PVF substrate film. Further, the ink total failure probably occurs at approximately the same number of cycles for both films.

5.4.2 ADDITIONAL PROPERTIES

One additional test was performed: decorative capability. Specimens were submitted to Walter Dorwin Teague Associates for evaluation of their aesthetic qualities. Results of this evaluation are described in the following three paragraphs and in table 47.

An evaluation of the 10 trial laminates brought about several general observations. Using System A-1 as a baseline, it was noted that the white background was quite clean. In other laminates, where the backside resin was yellow, discoloration of the white field on the film side towards a yellow tint was observed.

In all cases where PVF/PC was a component, the canvas embossed texture was more accentuated. This phenomenon is due to the formability of polycarbonate and was demonstrated here in its excellent capacity for reproducing texture even to a degree that, in this case, is a detriment, as flaws in the embossing blanket were reproduced and "cut-through" was experienced.

In the case of System B-5, it was observed that the extreme formability of the polycarbonate, produced small dark spots at the base of the "pits" in the canvas texture. This effect is undesirable and causes an overall darkened appearance.

5.5 TASK 5

At the conclusion of Tasks 1, 2, 3, and 4, face sheet materials, adhesive plies, honeycomb core, and decorative film materials were selected for combining into the final total decorative sandwich panel system for verification testing in Task 5. In addition, a foam-filled core was selected to be included in the final phase based on supplemental testing. Table 48 and figure 72 show the baseline and candidate composite sandwich panel systems that were selected for Task 5 testing.

Selection of the face sheet, adhesive ply, and honeycomb core materials was accomplished following completion of Tasks 1 and 2. The selection was based on a ranking precedure developed specifically for this program. See appendix B for details of the ranking procedure.

Likewise, a similar ranking procedure was used to select a foam-filled core. The ranking was based on data from supplemental testing. See appendix C for both the analysis of the

supplemental test data and details of the ranking procedure.

Tests were selected to verify that the new decorative sandwich panels (Panels No. 2 and 3) possessed improved flammability characteristics when compared to the baseline epoxy system (Panel No. 1). The tests will be discussed individually in the following paragraphs.

5.5.1 SMOKE EMISSION

The smoke emission of the panels was measured in two test apparatuses: the NBS smoke chamber, which is a closed, noncirculating accumulation chamber, and the Ohio State Release Rate apparatus, which is closed but has a controlled amount of air that is ducted over the surface of the specimen. Both apparatuses were operated over a range of heat fluxes to fully characterize the response of the materials. Figures 73-80 are graphical representations of the data contained in tables 49-52.

Figures 81-83 contain photographs of some of the specimens following testing.

In all cases, the smoke release rate and specific optical density increased for both apparatuses as the heat flux was increased. This increase is due to more material becoming involved in the combustion at higher heat fluxes. The smoke emission characteristics of both the phenolic resin panels (i.e., including foam-filled) showed a definite improvement over the baseline epoxy panel.

5.5.2 HEAT RELEASE

The amount and rate of heat release were measured using the OSU Release Rate apparatus run at heat fluxes of 1.0 to 5.0 W/cm^2 (52.9 to 264.3 Btu/ft^2/min) with specimens mounted in a horizontal as well as vertical mode. Figures 84-87 are graphical representations of the data contained in tables 53 and 54.

Figures 88 and 89 contain photographs of some of the specimens following testing.

In all cases, the total heat release and maximum rate of heat release for all the systems increased as the incident heat flux was raised from 1.0 to 5.0 W/cm^2 (52.9 to 264.3 Btu/ft^2/min). The data show the total heat released from the phenolic panels to be approximately the same as that released from the baseline epoxy panels. This is attributed to the large quantity of heat contributed by the honeycomb core and decorative film compared to the heat released by the resin-impregnated fiberglass face sheets.

5.5.3 FLAME PENETRATION

The flame penetration provides another means of measuring heat release. As described in appendix A (sec. A.7), the flame penetration test exposes the specimen to an open flame, high heat flux condition; i.e., 8-9 W/cm^2 (422.9-475.8 Btu/ft^2/min). Figures 90-92 are graphical representations of the data contained in tables 55 and 56. In addition to the data presented, photographs of typical test specimens were made and are presented in figure 93.

Under exposure to the conditions of this test, both phenolic panels (Panels No. 2 and 3) release less heat than the baseline epoxy panel. In addition, the maximum heat release rate of the phenolic panels was less than the baseline epoxy panel.

Addition of phenolic foam to the core decreased the heat transmitted through the panel, as illustrated in figure 92. The backface temperature rise of Panel No. 2 was greater than Panel No. 1, which was expected based on Task 2 test results (see fig. 44).

5.5.4 TOXICITY CHARACTERISTICS

Toxic gas evolution was measured by sampling the gases as collected in the NBS smoke chamber during the smoke emission test. Figures 94-96 are graphical representations of the data contained in tables 57 and 58.

The gas samples showed relatively low levels of CO and HCN. The phenolic systems produced higher quantities of each gas at 5.0 W/cm^2 (264.3 Btu/ft^2/min) when compared to the epoxy baseline panel. See figures 94 and 96.

HF evolution increased with increasing heat flux (see fig. 95) for both flaming and smoldering conditions. It is interesting to note that, when compared to flaming conditions, less HF was detected at 1.0 W/cm^2 (52.9 Btu/ft^2/min) in the smoldering mode, while significantly more HF was detected at 5.0 W/cm^2 (264.3 Btu/ft^2/min) in the smoldering mode.

5.5.5 MECHANICAL PROPERTIES

Peel strength, flatwise tensile strength, and beam flexure tests were run on each of the sandwich panels. Figures 97 and 98 are graphical representations of the data contained in tables 59 and 60. Table 61 contains the beam flexure test results. In addition to the data presented, photographs of typical flatwise tensile test specimens were made and are presented in figure 99.

Results show that all sandwich panels tested possessed acceptable levels of mechanical strength. Panels No. 1 and 2 appear to have low peel strengths (see fig. 97) when compared to the goal of 11.5 cm-kg/7.62-cm width (10.0 in.-lb/3-in. width). This phenomenon is attributed to the large thickness of the honeycomb core and, in all cases, the peel strengths are considered adequate.

In addition, an abrasion test was run to determine the effect of substrate material on the wear characteristics of the decorative film (viz., PVF/PVF). Table 62 contains the test data.

Based on weight loss, the Taber abrasion test showed Panels No.1 and 2 to be more susceptible to wear than Panel No. 3. From a durability standpoint (cycles to failure), Panel No.3 exhibited total failure sooner than either Panel No.1 or Panel No. 2.

6.0 CONCLUSIONS

Propensity to burn, smoke emission, toxic gas emission, and heat release can be lowered by utilizing modified phenolic resins in place of epoxy. See table 63. All three modified phenolic resin systems exhibited an improvement over the baseline epoxy from the standpoint of flammability, smoke, and toxicity. Also, the addition of 40.0 kg/m^3 (2.5 lb/ft^3) phenolic foam to the core provided improved burn-through characteristics.

Acceptable mechanical, wear, and cleanability properties were also exhibited by the phenolic resins. However, an unsatisfactory discoloration of the decorative ink system occurs during the fabrication of decorative laminates as shown by the results in Task 4.

7.0 MATERIAL AND PROCESS SPECIFICATIONS

A tentative specification covering the requirements of resin-impregnated fiberglass face sheet and bond ply materials has been prepared and is shown in appendix D. Also, a tentative specification covering the requirements of fabricating interior sandwich panels has been prepared and is shown in appendix E. Both of these specifications are based on the materials that were developed under this contract. Some of the tests referred to in the specifications were not covered under the contract work statement, but were considered to be necessary for inclusion.

8.0 FUTURE WORK

The testing in Task 3 and 4 indicated a need for : (1) an improved decorative film and (2) further studies to develop a modified phenolic system which would eliminate the unsatisfactory discoloration of the decorative ink system during fabrication. The PVF/PVF System produced an undesirable amount of HF and the PVF/PC system, which reduced the HF emission, was susceptible to embrittlement. None of the films were considered superior from the testing. Therefore, PVF/PVF was chosen as the decorative film for Task 5. At the present time, there is a definite need to develop a film with an LOI greater than 40, with good elongation characteristics and resistance to embrittlement.

The area of test method selection for laboratory evaluation is still clouded. Simple laboratory tests such as TGA and DTA do not accurately reflect the behavior of materials under flaming conditions. More sophisticated laboratory tests such as the Ohio State Release Rate or high-heat-flux NBS chamber tests are needed to select materials, and these are costly tests to perform. Also, these sophisticated tests require full-scale testing to verify their acceptability.

Given the potential improvements in fire resistance indicated by this report, it is now necessary to move from the laboratory-scale testing to full-scale testing for verification.

APPENDIX A
DETAILS OF TEST PROCEDURES

A.1 60-SECOND VERTICAL FLAMMABILITY

The FAR 25-32 flammability tests are required by the FAA for flight hardware certification. In accordance with FAR 25-32 (see ref. 14), the 60-second vertical ignition test was conducted. The procedure is described in the following paragraphs and a typical test setup is shown in figures 2 and 3.

The Bunsen burner was operated on commercial propane gas supplied from a storage tank at a line pressure of 26.67 cm (10.5 in.) of water. The flame was adjusted to give a temperature of 871 $\pm$ 10°C (1600 $\pm$ 50°F) with a flame height of 38.1 mm (1.5 in.) total and a blue cone height of 19.05 mm (0.75 in.). Flame temperature was measured by using a Leeds & Northrop model 8659 bridge-type potentiometer and chromel-alumel thermocouple that was mounted to the specimen holder flame for accurate positioning during the measurement.

The specimens were mounted vertically as shown in figure 3. Three specimens of each material were tested at these conditions. The time during which the burner flame was applied to the specimen and the time of specimen burning following removal of the burner flame were measured by using an electric timer accurate to within 0.1 second. Burned length was determined by measurement with a steel scale graduated in 0.025-cm (0.01-in.) increments. The test specimens were 7.62 cm (3 in.) wide by 33 cm (13 in.) long and were conditioned prior to testing for a minimum of 24 hours at 26 $\pm$ 1.5°C (78 $\pm$ 3°F) and 50% relative humidity.

A.2 LIMITING OXYGEN INDEX (LOI)

Limiting Oxygen Index tests were performed in the oxygen-nitrogen test apparatus shown in figures 4 and 5. The tests were conducted in conformance with ASTM D2863 (ref. 15) except as noted below.

The method of operation was to select the initial concentration of oxygen based on past experience with similar materials. The gases were allowed to flow for 30 seconds to purge the system. The specimen was ignited so that the entire tip was burning. The relative flammability was determined by adjusting the concentration of gases rising past the specimen to a point where the oxygen concentration was at the minimum that would allow the specimen to burn; i.e., the specimen burns 3 minutes or longer or burns 50 mm (2 in.). Volumetric flow of the oxygen and nitrogen gases was measured by calibrated glass flowmeters. The oxygen index was calculated by the following formula:

$$LOI = \frac{(100)\ (V_{f1})}{V_{f1} + V_{f2}}$$

where V_{f1} and V_{f2} are the volumetric flow rates in cm^3/sec of O_2 and N_2, respectively.

The length and width of the specimens were as specified in ASTM D2863. Thickness of the specimens varied and often was different from that specified in ASTM D2863; however, the thickness of each individual class of material tested was the same (i.e., skin, bond ply, core, etc.).

A.3 NBS SMOKE CHAMBER

Smoke and toxic gas generation were determined in an accumulating chamber of the design used by the National Bureau of Standards and described in NBS Technical Note 708 (ref. 17). The test equipment and operation are described in the following paragraphs.

The test chamber is a sealed metal box 0.91 m (3 ft) wide by 0.61 m (2 ft) long by 0.91 m (3 ft) high with a total capacity of 0.51 m^3 (18 ft^3). The test chamber contains a furnace, specimen holder, and photometer system and has provision for the attachment of a gas burner. The chamber is shown in figures 6 and 7.

The photometric system consists of a high-intensity light source and photocell. The light path is vertical within the chamber in order to reduce errors arising from smoke stratification. A sensitive amplifier with large meter scales for accurate readings is supplied as the readout system and, by this means, values of light transmittance are obtained. A recorder is connected to the meter so that a continuous plot of transmittance is obtained.

The percentage change in the light transmission is converted to an optical density value by means of the following equation:

$$D_S = \frac{V}{AL} \log_{10} \left(\frac{100}{T}\right)$$

where: D_S = specific optical density

V = chamber volume, 0.51 m^3 (18 ft^3)

L = light path length, 0.91 m (3 ft)

A = exposed test specimen surface area, 42.35 cm^2 (6.56 $in.^2$)

T = percent transmission

The test specimen size was approximately 7.62 x 7.62 cm (3 x 3 in.). The back, edges, and unexposed front surface of the specimen were covered by a single sheet of aluminum foil. The foil-protected specimens were then backed by a 7.62- x 7.62- x 1.27-cm (3- x 3- x 0.5-in.) sheet of asbestos millboard. The use of asbestos sheet minimizes the heat loss through the rear of the specimen. The microjet gas burner was placed in front of the radiant furnace so that the jets impinged on the bottom surface of the specimen. The air/propane mixture was adjusted to the correct ratio and flow rate by the adjustment of two independent flowmeters. The specimen was then slid across into the heat path of the furnace and in front of the gas jets and burning commenced. After completion of each test, the cabinet was vented and the photocell cleaned. A minimum of three specimens were tested at each radiant heat flux; viz., 1.0 W/cm^2 (52.9 $Btu/ft^2/min$), 2.5 W/cm^2 (132.2 $Btu/ft^2/min$), and 5.0 W/cm^2 (264.3 $Btu/ft^2/min$).

The specimen under test is irradiated by means of an electrically heated radiant energy source mounted within an insulated ceramic tube, positioned so that the desired irradiance level averages over the central 3.81-cm (1.5-in.) diameter area of the vertically mounted specimen. The irradiance level is determined by the applied voltage to the furnace, which is controlled by a rheostat.

The gas burner has six flamelets, three of which are directed horizontally at right angles to the sample surface. Three are canted downward to impinge normally on the specimen surface.

The specimen holders, fabricated from stainless steel, are designed to expose a 6.51-cm (2.562-in.) square specimen area to the radiant heat of the furnace. The gas jets emerge along the bottom edge of the specimen.

The specimen, supported as previously described, is located vertically, 3.81 cm (1.5 in.) in front of the furnace opening. A 7.62-cm (3-in.) square of asbestos millboard is used to back the specimen and the whole assembly is retained by a bent spring of phosphor bronze sheet and a steel retaining rod.

Toxic gas generation was determined quantitatively by using colorimetric (Dräger) tubes, sodium hydroxide (NaOH) absorber solutions, and on-line gas detectors. Each Dräger tube was designed by the manufacturer to measure a specific type of gaseous product. The NaOH solutions were analyzed using specific ion electrode.

A.4 OSU RELEASE RATE APPARATUS

Heat and smoke release characteristics were determined using the OSU Release Rate apparatus. The test equipment (figs. 8 and 9) and operation are described in the following paragraphs.

The temperature difference between the air entering the environmental chamber and that leaving was monitored by a thermopile for heat release calculations. A photometer measured the percent of light transmitted through the gases leaving the apparatus for smoke release calculations. An electrically heated panel was used as the radiant heat source.

Two different types of specimen holders were used: one for 152- x 152-mm (6- x 6-in.) specimens tested in a vertical orientation and the other for 102- x 254-mm (4- x 10-in.) specimens tested in a horizontal orientation. The unexposed surfaces of the specimens were covered with aluminum foil.

A pilot flame was used as the ignition source for the specimens tested. The flame was positioned 10 mm (0.4 in.) from and perpendicular to the exposed surface of the vertical specimens. The centerline at the outlet of the pilot burner tube intersected the vertical centerline of the vertical specimens 5 mm (0.2 in.) above the lower edge. In the case of the horizontal specimens, the flame was positioned 10 mm (0.4 in.) above and perpendicular to the exposed surface. The end of the pilot burner tube was located 10 mm (0.4 in.) above and at the center of the horizontal specimen.

The specimens that were vertically mounted measured 152 x 152 mm (6 x 6 in.) and the specimens that were horizontally mounted measured 102 x 254 mm (4 x 10 in.) in size. The specimens were conditioned for 24 hours in an oven at 60°C (140°F) and then placed in a cabinet at 50% relative humidity and 26°C (79°F) for a minimum of 24 hours prior to testing. Three specimens from each panel were tested at each orientation (viz., horizontal and vertical) and each heat flux; viz., 1.0 W/cm^2 (52.9 $Btu/ft^2/min$), 2.5 W/cm^2 (132.2 $Btu/ft^2/min$), and 5.0 W/cm^2 (264.3 $Btu/ft^2/min$).

The pilot flame was ignited and positioned. The radiant panel was set for the desired heat flux. The air flow to the equipment was set at 2.38 $\pm$ 0.11 m^3/min (84 $\pm$ 4 ft^3/min) for atmospheric pressure and 23.3°C (74°F) temperature conditions. Steady-state conditions, such that the radiant heat flux did not change more than 0.511 kW/m^2 (0.045 $Btu/ft^2/sec$) over a 10-minute period, were maintained before the specimen was injected.

The specimen was placed in the hold chamber with the radiation shield doors closed. The airtight outer door was secured, recording devices started, and output of the thermopile and smoke detector set to "zero" on the recorder. The specimen was retained in the hold chamber 60 $\pm$ 5 seconds before ignition.

Normally the test duration was about 10 minutes; however, in some cases the test was terminated when heat and smoke release ceased. A blank run (baseline test) was performed during which the specimen holder, with a piece of asbestos in place of a specimen, was injected and heat release versus time data taken.

The total smoke and heat release are calculated by integrating the light transmission loss and temperature rise, respectively, over the length of the run.

$$\text{Total Smoke Emission} = D_M = \frac{V}{AL} \int_0^t \log_{10} \left(\frac{100}{Kt}\right) \frac{T_o}{T_I} \, dt$$

$$\text{Total Heat Evolved} = H_T = \frac{C_K}{A} \int_0^t T_o dt$$

where:

- t = time
- C_K = constant (function of V, T_I, and heat flux)
- V = volume of air, 2.4 m^3/min (85 ft^3/min)
- A = area of sample; vertical = 232.3 cm^2 (0.25 ft^2), horizontal = 260.1 cm^2 (0.28 ft^2)
- L = length of light path
- K = percent of light transmission
- T_I = inlet temperature
- T_o = outlet temperature

A.5 PYROLYSIS TUBE DECOMPOSITION – 600°C (1112°F)

A sample of material to be tested was placed in a quartz or Monel tube and heated in a tube furnace to 600°C (1112°F). Air was passed through the tube at 400 cm^3/min (0.014 ft^3/min) and the effluent gases were captured in NaOH absorber solutions. The resulting NaOH solutions then were analyzed by suitable methods such as specific ion electrode.

A.6 NASA ANIMAL EXPOSURE CHAMBER

Relative toxicity tests were conducted utilizing the NASA animal exposure chamber shown in figure 10 in order to determine the relative toxicity of the candidate materials. The chamber is constructed from polymethylmethacrylate and has a total free volume of 4.2 liters (256.3 $in.^3$); 2.8 liters (170.9 $in.^3$) are available for animal occupancy. The chamber is fitted with probes for pyrolysis gas sampling and for an oxygen analyzer. In addition, the temperature in the chamber is monitored utilizing the thermometer indicated.

The upper dome section is removable and is connected to the base section by means of a conventional toggle snap ring; the joint is sealed by an O-ring. The upper end of the dome section is provided with an aperture so that test gas can flow completely through the chamber if desired, using the gas inlet passage in the base as the other aperture. In these experiments, the gas outlet was connected to a bubbler to permit venting of pressure exceeding 2.54 cm (1.00 in.) of water and to prevent entry of fresh air.

The sample material was pyrolyzed in a quartz tube closed at one end with a cap and connected at the other end to the animal exposure chamber. A horizontal tube furnace was used for pyrolysis and the pyrolysis effluents were conveyed to the animal exposure chamber by normal thermal flow. A perforated plate or barrier of polymethylmethacrylate prevents movement of mice into the pyrolysis or connecting tube. The chamber design and the activity of the freely moving mice promote distribution of gases within the chamber. A connecting tube between the furnace and the chamber was utilized, which reduced the possibility of a significant temperature in the animal exposure chamber and reduced conduction of heat to the chamber itself, but it also represented dead space and additional travel distance and provided opportunity for condensation and absorption on the inner surface of the tube and absorption in any condensate present.

Four Swiss albino male mice, 25 to 35 grams (0.055 to 0.077 lb) body weight, were used for each test. The mice were placed in the animal exposure chamber and given a minimum of 5 minutes to adjust themselves to their surroundings. With both sample and animals in place, the entire system was sealed and all joints checked for proper seating. The animal exposure chamber was the last part sealed to minimize oxygen consumption before the actual start of the test.

The furnace was preheated to 200°C (392°F) and at the start of the test was turned on at a predetermined heating rate of 40°C/min (72°F/min). When the upper temperature limit of 800°C (1472°F) was attained, it was maintained by either automatic or manual control until the end of the test. The test period was normally 30 minutes. If 100% mortality occurred in less than 30 minutes, the test was terminated upon the death of the last surviving animal.

The apparent lethal concentration for 50% of the animals, ALC_{50}, was calculated and is defined as that concentration of gaseous pyrolysis products in the atmosphere being inhaled, evolved under these specific test conditions, that will produce death in 50% of the test animals.

A.7 BOEING BURN-THROUGH

Resistance of the candidate panels to penetration by a 1093°C (2000°F) flame was determined in the Boeing test apparatus shown in figures 11-15. The operating conditions during the tests and the test procedure are described in the following paragraphs.

The operating conditions were adjusted to provide a heated gas temperature of 1093 $\pm$ 55.6°C (2000 $\pm$ 100°F) and an incident heating rate of 8.5-10.2 W/cm^2 (7.5-9.0 Btu/ft^2/sec) at the position of the center of the exposed face of the test specimen. Initial settings were made with a Hycal water-cooled calorimeter mounted through a hole in an insulating baffle placed in the test specimen position.

The gas temperature was measured by the platinum-platinum (13%) rhodium thermocouple shown in figure 13 located in front of the center of the specimen window. Thermocouple and calorimeter outputs were recorded by the Varian recorder shown in the lower right-hand corner of figure 12. The heating source was a Meeker blast burner fed with commercial propane gas premixed with air at the burner. The gas was fed at 26.67 cm (10.5 in.) of water pressure.

The heat release was calculated by comparing the increase in temperature of the exhaust (stack) gases during the period the material burned or pyrolyzed (reacted) with the increase of the exhaust gas temperature produced by using a piece of asbestos board (dummy) in place of the test specimen.

The test specimens were 11.1-cm (4.375-in.) squares of the sandwich panel. The specimens were conditioned for 24 hours in an oven at 60°C (140°F) and then placed in a cabinet at 50% relative humidity and 26°C (79°F) for a minimum of 24 hours prior to testing. At least three specimens from each panel were tested.

The gas flow rate was measured by a Fischer-Porter flowmeter. The premix air was fed at 0.7 kg/cm^2 (10 $lb/in.^2$) pressure. The perforated plate airflow was measured by a Fischer-Porter flowmeter. In operation, the gas flow and the perforated plate airflow were kept constant. The premix air was adjusted to give the proper flame temperature and heating rate.

The insertion door operates a microswitch that marks the opening and closing on the recorder chart. The door also operates a lever mechanism that moves a chromel-alumel thermocouple into contact with the unexposed (backface) side of the test specimen.

The tester was brought to the proper operating conditions with the specimen insertion door closed, the flame baffle in position in the test specimen window (shown in this position in figure 15), and a glass wool filter in place in the wire tray shown at the top of the chimney. The test specimen, conditioned as described previously, was placed into a picture-frame holder. The recorder chart was started. The door was opened and the test specimen was inserted, pushing the baffle out of a slot in the opposite wall. The door was closed. The outputs from the flame temperature thermocouple, the backface temperature thermocouple, and the exhaust gas temperature thermocouple were continuously drawn on the recorder chart throughout the test.

A.8 THERMAL ANALYSES

Differential thermal analysis (DTA) and thermogravimetric analysis (TGA) tests were performed simultaneously on the same sample of material. The Mettler Thermoanalyzer was employed in an air environment with a heating rate of 10°C/min (18°F/min). Analytical results were in the form of specimen weight remaining in milligrams versus temperature in °C (TGA) and total amount of energy given off during specimen decomposition in calories/gram (DTA).

A.9 PEEL STRENGTH (HONEYCOMB)

The peel strength was determined by peeling the face skin and back skin from the honeycomb core. The test was performed in accordance with ASTM D1781 (ref. 18) except that the specimens were not conditioned prior to testing. Specimen size was 76.2 x 304.8 mm (3 x 12 in.) with the 304.8-mm (12-in.) dimension parallel to the fabric warp direction and head speed was 2.54 cm/min (1.00 in./min). A minimum of three specimens of each panel were tested. The peel strength for each individual test was calculated as follows:

$$S_P = (R_0 - R_1)\,(F_1 - F_0)$$

where: S_P = peel strength

R_0 = radius of the flange, to the center of the strap

R_1 = radius of the drum

F_1 = average load after the first 50.8 mm (2 in.) of facing has been peeled

F_o = correction for the load required to overcome the weight of the drum

A.10 PEEL STRENGTH (FILM)

The peel strength was determined by peeling the top film from the substrate film and by peeling the composite decorative film from the fiberglass prepreg. These tests were performed in accordance with ASTM D903 (ref. 19) except that the specimens were not conditioned prior to testing.

A.11 BEAM FLEXURE

The compression strength of the sandwich panels was determined by testing according to MIL-STD-401 (ref. 20). Test specimens were 76.2 x 609.6 mm (3 x 24 in.) with the 609.6-mm (24-in.) dimension parallel to the core ribbon direction of the panel. Any values from specimens that failed at or under the load points or by core shear, adhesion, or tension were not included in the calculations. Figure 100 shows the test apparatus schematic.

The compressive stress was determined on the specimens through the following calculation:

$$S_c = \frac{Pd}{2w\left(C_T + \frac{t_t + t_c}{2}\right)}$$

where: S_c = compressive stress, kg/cm (lb/in.)

P = failure load, kg (lb)

d = distance from support post to load post, 22.86 cm (9 in.)

w = specimen width, 7.62 cm (3 in.)

t_c = compression face thickness, 0.03937 cm (0.0155 in.)

t_t = tensile face thickness, 0.03937 cm (0.0155 in.)

C_T = core thickness, 2.413 cm (0.95 in.)

Modulus was determined on the specimens through the following calculation:

$$M = P/Y \cdot \frac{d(3L^2 - 4d^2)}{48w \left(\frac{t_c t_t}{t_c + t_t} \right) \left(h - \frac{t_c + t_t}{2} \right)^2}$$

where: M = modulus, kg/cm^2 (lb/in.^{2})

P/Y = slope of initial portion of load-deflection curve, kg/cm (lb/in.)

d = distance from support post to load post, 22.86 cm (9 in.)

L = span between lower support posts, 55.88 cm (22 in.)

w = specimen width, 7.62 cm (3 in.)

t_c = compression face thickness, 0.03937 cm (0.0155 in.)

t_t = tensile face thickness, 0.03937 cm (0.0155 in.)

h = total sandwich panel thickness, 2.492 cm (0.981 in.)

A.12 FLATWISE TENSILE STRENGTH

Flatwise tensile strength was determined by testing according to MIL-STD-401 (ref. 20). Test specimens were cut 50.8 x 50.8 mm (2 x 2 in.) and tested after being bonded between two steel cubes 50.8 x 50.8 x 50.8 mm (2 x 2 x 2 in.). The adhesive used was EC 2216, which is a modified epoxy manufactured by the Minnesota Mining and Manufacturing Company. Testing speed was 0.127 cm/min (0.05 in./min). Five specimens of each panel were tested.

A.13 FABRIC WEAR

The rate of wear was determined on the decorative films by the oscillatory cylinder (Wyzenbeek) method; i.e., FTMS No. 191, Method 5304.1 (ref. 21). Emery cloth, 600 grit-soft, was used as the abradant in place of No. 0 emery paper. The number of cycles to decorative ink failure was recorded rather than the change in breaking strength.

A.14 TABER ABRASION

The rate of wear was determined on the decorative films by testing according to FTMS No. 406, Method 1091 (ref. 22) using a Taber abraser. CS-10 Calibrase wheels were used for testing; however, the load per wheel was 0.5 kg (1.1 lb) rather than 1.0 kg (2.2 lb) specified in the method. Two parameters were mesaured: (1) cycles to decorative ink failure, and (2) total weight loss at decorative ink failure.

A.15 ELONGATION

An Instron testing machine was used, which has a constant-rate-of-cross-head-movement. There is a fixed, or essentially stationary, member carrying one grip and a movable member carrying a second grip. The grips also have a self-alignment capability. Test specimens were cut with a Die C cutter, which is described in ASTM D412 (ref. 23). The grip separation speed was 12.7 mm/min (0.5 in./min). Five specimens of each material were tested.

A.16 IMPACT STRENGTH

Impact strength was determined using the Gardener impact test fixture shown in figure 101. The impact point was a steel rod tapered conically to a 3.175-mm (0.125-in.) flat face at the panel contact end as shown in figure 102. The projectile was a 0.91-kg (2-lb) weight to achieve failure impact force. The failure force was taken to be the minimum force at which the impact tool punctured the face sufficiently to permit a freshly sharpened writing pencil point to pass completely through the face sheet at the point of impact under light hand pressure.

A.17 DENSITY

Densities of the sandwich panels were determined by measuring the dimensions of the test specimen and then weighing the specimen. Results were expressed either as weight per unit area or weight per unit volume.

A.18 STAIN RESISTANCE

A sample of material at least 25.4 x 25.4 cm (10 x 10 in.) was soiled with the following items, allowed to dry for at least 2 hours, and then evaluated after cleaning. Each item was used to soil an area of about 32.3 cm^2 (5 $in.^2$).

Butter (any brand)

Mayonnaise (any brand)

Chocolate (a syrup or melted chocolate, any brand)

Fruit (orange juice, any brand)

Cleaning of the test panels, as mentioned above, was accomplished by the procedures outlined in the following paragraph.

Dilute one part of Kelite Spraywhite B with three parts by volume of water. Apply the solution to soiled specimen and brush vigorously for 0.5 to 2 minutes with a short stiff-bristled brush. A satisfactory brush can be made from a 12.7-mm (0.5-in.) or 25.4-mm (1-in.) paint brush by cutting the bristles to a length of about 12.7 mm (0.5 in.). Rinse off the solution with a water-moistened cloth and wipe dry with a clean cloth. The cleaning solution and rinse water shall be applied from dispensing containers such as polyethylene spray bottles and polyethylene wash bottles.

NOTE: Kelite Spraywhite B is a product of Kelite Corporation, Berkeley Heights, New Jersey.

A.19 ULTRAVIOLET STABILITY

Ultraviolet stability was determined by the procedure described in FTMS No. 191, Method 5660.2 (ref. 24). Condition of the test specimens was determined at the end of 20, 80, 140, and 295 hours of exposure.

A.20 DECORATIVE CAPABILITY

The aesthetic qualities of each of the candidate films were determined by making decorative laminates with the candidate resin systems and having Walter Dorwin Teague Associates, Incorporated, evaluate the resultant laminates. The test included evaluation of background color, opaqueness, cut-through, and texture.

APPENDIX B
RANKING PROCEDURES AND RESULTS

This appendix describes the ranking procedures used for the Task 2 sandwich panels and lists the results.

B.1 METHOD 1

This method utilizes a weighted average approach. The procedure has been broken down into a series of steps with a sample calculation.

STEP 1

Test data were selected from Task 2 for use in the calculations. Data from the following tests were used:

Limiting Oxygen Index (LOI)

Smoke Emission (NBS chamber)

Toxic Gas Emission (NBS chamber)

Total Heat Release (Boeing burn-through)

Maximum Heat Release Rate (Boeing burn-through)

Backface Temperature Rise (Boeing burn-through)

Total Heat Release (OSU-vertical)

Total Heat Release (OSU-horizontal)

Maximum Heat Release Rate (OSU-vertical)

Maximum Heat Release Rate (OSU-horizontal)

Smoke Emission (OSU-vertical)

Smoke Emission (OSU-horizontal)

Total Heat Release (DTA)

Peel Strength

Flatwise Tensile Strength

Impact Strength

Density

STEP 2

Data were tabulated in a convenient form prior to calculations. The tabulations are shown in tables 64-80.

STEP 3

Normalized composite values were calculated for each system; i.e., each of the systems was identified with 17 values, one for each of the parameters listed above (viz., LOI, Peel Strength, Density, etc.). The objective was to obtain a numerical rating between 0 and 1 for each system where 1 represented the best and 0 the worst. This way, the systems could be compared within one test and a composite value representing all tests could subsequently be calculated.

The following equations were employed to calculate the tabulated data in table 81. It can be seen from the equations below that all data within one test (i.e., Peel Strength, Density, etc.) were weighted equally.

$$A_1 = \frac{FS + BP + AD + C + F + AD + BP + BP}{100i}$$

where: A_1 = normalized composite LOI

FS = LOI of face sheet

BP = LOI of bond ply

AD = LOI of adhesive

C = LOI of core

F = LOI of foam

i = number of terms in the numerator

For example, consider System 5 (see table 64):

$$A_1 = (50.7 + 32.3 + 30.9 + 23.0 + 32.3 + 32.3) \div (100)(6)$$

$$A_1 = 0.336$$

$$A_2 = 1 - \frac{S_{NUU} + S_{NUX} + S_{NUZ}}{180} - \frac{S_{NXU} + S_{NXX} + S_{NXZ}}{900} - \frac{S_{NZU} + S_{NZX} + S_{NZZ}}{1800}$$

where: A_2 = normalized composite Smoke Emission (NBS chamber)

S_{NUU} = D_S at 1.0 W/cm^2 (52.9 Btu/ft^2/min) and 1.5 min

S_{NUX} = D_S at 1.0 W/cm^2 (52.9 Btu/ft^2/min) and 4.0 min

S_{NUZ} = maximum D_S at 1.0 W/cm^2 (52.9 Btu/ft^2/min)

S_{NXU} = D_S at 2.5 W/cm^2 (132.2 Btu/ft^2/min) and 1.5 min

S_{NXX} = D_S at 2.5 W/cm^2 (132.2 Btu/ft^2/min) and 4.0 min

S_{NXZ} = maximum D_S at 2.5 W/cm^2 (132.2 Btu/ft^2/min)

S_{NZU} = D_S at 5.0 W/cm^2 (264.3 Btu/ft^2/min) and 1.5 min

S_{NZX} = D_S at 5.0 W/cm^2 (264.3 Btu/ft^2/min) and 4.0 min

S_{NZZ} = maximum D_S at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

For example, consider System 5 (see table 65):

$$A_2 = 1 - [(0.0 + 0.0 + 0.0) \div 180] - [(0.5 + 1.20 + 20.6) \div 900] - [(15.3 + 23.9 + 38.4) \div 1800]$$

$$A_2 = 0.932$$

$$A_3 = \frac{COU + COX + COZ}{3500} - \frac{HCNU + HCNX + HCNZ + XHCN}{140}$$

where:

A_3 = normalized composite Toxic Gas Emission (NBS chamber)

COU = CO concentration at 1.0 W/cm^2 (52.9 Btu/ft^2/min) and 4.0 min

COX = CO concentration at 2.5 W/cm^2 (132.2 Btu/ft^2/min) and 4.0 min

COZ = CO concentration at 5.0 W/cm^2 (264.3 Btu/ft^2/min) and 4.0 min

HCNU = HCN concentration at 1.0 W/cm^2 (52.9 Btu/ft^2/min) and 4.0 min

HCNX = HCN concentration at 2.5 W/cm^2 (132.2 Btu/ft^2/min) and 4.0 min

HCNZ = HCN concentration at 5.0 W/cm^2 (264.3 Btu/ft^2/min) and 4.0 min

XHCN = HCN concentration at 2.5 W/cm^2 (132.2 Btu/ft^2/min) and 10.0 min

For example, consider System 5 (see table 66):

$$A_3 = 1 - [(81.0 + 120.0 + 403.0) \div 3500] - [(1.0 + 2.0 + 5.0 + 5.0) \div 140]$$

$$A_3 = 0.735$$

$$A_4 = 1 - \frac{BTT}{800}$$

where: A_4 = normalized composite Total Heat Release (Boeing Burn Through)

BTT = total heat release

For example, consider System 5 (see table 67):

$$A_4 = 1 - (569.6 \div 800)$$

$$A_4 = 0.288$$

$$A_5 = 1 - \frac{BTR}{10}$$

where:

A_5 = normalized composite Maximum Heat Release Rate (Boeing Burn Through)

BTR = maximum heat release rate

For example, consider System 5 (see table 68):

$$A_5 = 1 - (4.1 \div 10)$$

$$A_5 = 0.590$$

$$A_6 = 1 - \frac{BFT}{500}$$

where:

A_6 = normalized composite Backface Temperature Rise (Boeing Burn Through)

BFT = backface temperature at the end of 4.0 min

For example, consider System 5 (see table 69):

$$A_6 = 1 - (331 \div 500)$$

$$A_6 = 0.338$$

$$A_7 = 1 - \frac{VTU}{600} - \frac{VTX}{1800} - \frac{VTZ}{4500}$$

where: A_7 = normalized composite Total Heat Release (OSU-vertical)

VTU = total heat release at 1.0 W/cm^2 (52.9 $Btu/ft^2/min$)

VTX = total heat release at 2.5 W/cm^2 (132.2 $Btu/ft^2/min$)

VTZ = total heat release at 5.0 W/cm^2 (264.3 $Btu/ft^2/min$)

For example, consider System 5 (see table 70):

$$A_7 = 1 - (127.6 \div 600) - (275.5 \div 1800) - (515.1 \div 4500)$$

$$A_7 = 0.520$$

$$A_8 = 1 - \frac{HTU}{600} - \frac{HTX}{1200} - \frac{HTZ}{4500}$$

where: A_8 = normalized composite Total Heat Release (OSU-horizontal)

HTU = total heat release at 1.0 W/cm^2 (52.9 $Btu/ft^2/min$)

HTX = total heat release at 2.5 W/cm^2 (132.2 $Btu/ft^2/min$)

HTZ = total heat release at 5.0 W/cm^2 (264.3 $Btu/ft^2/min$)

For example, consider System 5 (see table 71):

$$A_8 = 1 - (129.0 \div 600) - (217.6 \div 1200) - (782.8 \div 4500)$$

$$A_8 = 0.430$$

$$A_9 = 1 - \frac{VRU}{3} - \frac{VRX}{15} - \frac{VRZ}{45}$$

where:

A_9 = normalized composite Maximum Heat Release Rate (OSU-vertical)

VRU = maximum heat release rate at 1.0 W/cm^2 (52.9 Btu/ft^2/min)

VRX = maximum heat release rate at 2.5 W/cm^2 (132.2 Btu/ft^2/min)

VRZ = maximum heat release rate at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

For example, consider System 5 (see table 72):

$$A_9 = 1 - (0.5 \div 3) - (1.0 \div 15) - (6.4 \div 45)$$

$$A_9 = 0.624$$

$$A_{10} = 1 - \frac{HRU}{3} - \frac{HRX}{6} - \frac{HRZ}{30}$$

where:

A_{10} = normalized composite Maximum Heat Release Rate (OSU-horizontal)

HRU = maximum heat release rate at 1.0 W/cm^2 (52.9 Btu/ft^2/min)

HRX = maximum heat release rate at 2.5 W/cm^2 (132.2 Btu/ft^2/min)

HRZ = maximum heat release rate at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

For example, consider System 5 (see table 73):

$$A_{10} = 1 - (0.4 \div 3) - (1.2 \div 6) - (4.3 \div 30)$$

$$A_{10} = 0.523$$

$$A_{11} = 1 - \frac{VSTU + VSTX + VSTZ}{1200} - \frac{VSRU + VSRX + VSRZ}{120}$$

where: A_{11} = normalized composite Smoke Emission (OSU-vertical)

VSTU = D_M at 1.0 W/cm^2 (52.9 Btu/ft^2/min)

VSTX = D_M at 2.5 W/cm^2 (132.2 Btu/ft^2/min)

VSTZ = D_M at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

VSRU = $d(D_M)/dt$ at 1.0 W/cm^2 (52.9 Btu/ft^2/min)

VSRX = $d(D_M)/dt$ at 2.5 W/cm^2 (132.2 Btu/ft^2/min)

VSRZ = $d(D_M)/dt$ at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

For example, consider System 5 (see table 74):

$$A_{11} = 1 - [(0.0 + 5.2 + 70.4) \div 1200] - [(0.0 + 0.0 + 5.2) \div 120]$$

$$A_{11} = 0.894$$

$$A_{12} = 1 - \frac{HSTU + HSTX + HSTZ}{1200} - \frac{HSRU + HSRX + HSRZ}{120}$$

where: A_{12} = normalized composite Smoke Emission (OSU-horizontal)

HSTU = D_M at 1.0 W/cm^2 (52.9 Btu/ft^2/min)

HSTX = D_M at 2.5 W/cm^2 (132.2 Btu/ft^2/min)

HSTZ = D_M at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

HSRU = $d(D_M)/dt$ at 1.0 W/cm^2 (52.9 Btu/ft^2/min)

HSRX = $d(D_M)/dt$ at 2.5 W/cm^2 (132.2 Btu/ft^2/min)

HSRZ = $d(D_M)/dt$ at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

For example, consider System 5 (see table 75):

$$A_{12} = [(0.0 + 10.3 + 50.3) \div 1200] - [(0.0 + 0.1 + 2.0) \div 120]$$

$$A_{12} = 0.932$$

$$A_{13} = 1 - \frac{DFS + DB + DA + DC + DF + DA + DB + DB}{1000i}$$

where: A_{13} = normalized composite Total Heat Release (DTA)

DFS = total heat release of face sheet

DB = total heat release of bond ply

DA = total heat release of adhesive

DC = total heat release of core

DF = total heat release of foam

i = number of terms in the numerator

For example, consider System 5 (see table 76):

$$A_{13} = 1 - [(141.8 + 177.4 + 457.0 + 584.8 + 177.4 + 177.4)] \div [1000(6)]$$

$$A_{13} = 0.714$$

$$A_{14} = \frac{PF + PB}{60}$$

where: A_{14} = normalized composite Peel Strength

PF = peel strength of face skin

PB = peel strength of back skin

For example, consider System 5 (see table 77):

$$A_{14} = (10.7 + 11.5) \div 60$$

$$A_{14} = 0.370$$

$$A_{15} = \frac{FTS}{50}$$

where: A_{15} = normalized composite Flatwise Tensile Strength

FTS = flatwise tensile strength

For example, consider System 5 (see table 78):

$$A_{15} = 17.7 \div 50$$

$$A_{15} = 0.354$$

$$A_{16} = \frac{IS}{20}$$

where: A_{16} = normalized composite Impact Strength

IS = impact strength

For example, consider System 5 (see table 79):

$$A_{16} = 8.1 \div 20$$

$$A_{16} = 0.405$$

$$A_{17} = \frac{1}{2} + \frac{DT}{4} - \frac{DD}{8}$$

where: A_{17} = normalized composite Density

DT = panel thickness

DD = panel density

For example, consider System 5 (see table 80):

$$A_{17} = 0.5 + (0.691 \div 4) - (1.74 \div 8)$$

$$A_{17} = 0.455$$

STEP 4

A total assessment based on the laboratory test data was then determined by combining the values in table 81 for each of the 13 systems. The composite values in table 81 were combined using a weighted distribution shown in table 82.

The following equation was employed to calculate the data in table 83:

$$A_{LT} = \frac{A_1 + A_2 + A_3 + A_{17}}{10} + \frac{3(A_4 + A_7 + A_8 + A_9 + A_{10})}{50}$$

$$+ \frac{A_5}{12.5} + \frac{A_6}{25} + \frac{A_{11} + A_{12}}{20} + \frac{A_{13} + A_{14} + A_{15} + A_{16}}{50}$$

where: A_{LT} = normalized composite value based on laboratory testing

A_1-A_{17} = values from table 81

For example, consider System 5 (see table 81):

$$A_{LT} = [(0.336 + 0.932 + 0.735 + 0.455) \div 10]$$
$$+ [3(0.288 + 0.520 + 0.430 + 0.624 + 0.523) \div 50]$$
$$+ (0.590 \div 12.5) + (0.338 \div 25) + [(0.894 + 0.932) \div 20]$$
$$+ [(0.714 + 0.370 + 0.354 + 0.405) \div 50]$$

$$A_{LT} = 0.578$$

STEP 5

Cost of fabrication and cost of material were tabulated in table 84 for each of the systems. Data are based on System 1 (baseline epoxy); i.e., 1.00 manhour for fabrication, $1.00 for miscellaneous fabrication costs, and $100.00 for materials.

STEP 6

A normalized composite value was calculated for each system representing the total cost of fabrication and materials combined. The equation utilized for this, and a sample calculation, follow. See table 85 for the resultant values.

$$A_{18} = 1 - \frac{LH}{20} - \frac{MMC + MC}{4000}$$

where: A_{18} = normalized composite material and fabrication costs

LH = manhours of labor

MMC = miscellaneous material cost

MC = material cost

For example, consider System 5 (see table 84):

$$A_{18} = 1 - (1.00 \div 20) - [(1.60 + 197.73) \div 4000]$$

$$A_{18} = 0.900$$

STEP 7

The final step involves combining the normalized composite value based on laboratory testing (A_{LT}) and the normalized composite material and fabrication costs (A_{18}) and obtaining a total overall assessment of each material system (A_T). Table 86 contains the total overall assessment values.

The following equation was used to obtain the values in table 86 and it reflects a weighting of 85% laboratory testing and 15% cost.

$$A_T = 0.85\ A_{LT} + 0.15\ A_{18}$$

where: A_T = normalized total overall assessment

A_{LT} = normalized composite value based on laboratory testing

A_{18} = normalized composite material and fabrication costs

For example, consider System 5 (see tables 83 and 85):

$$A_T = (0.85)(0.578) + (0.15)(0.900)$$

$$A_T = 0.626$$

B.2 METHOD 2

This method utilizes a weighted geometric mean approach. The procedure is a variation of one reported by E. C. Harrington, Jr. (see ref. 25). The geometric mean approach has the advantage that the higher the value of any factor, the more sharply is its relative importance reduced. An arithmetic approach, such as Method 1 above, has the disadvantage that a good score for one characteristic can compensate for a low value of another. This method has been broken down into a series of steps with a sample calculation.

STEP 1

Test data were selected from Task 2 for use in the calculations. Data from the following tests were used:

Limiting Oxygen Index (LOI)

Smoke Emission (NBS chamber)

Toxic Gas Emission (NBS chamber)

Total Heat Release (Boeing Burn Through)

Maximum Heat Release Rate (Boeing Burn Through)

Backface Temperature Rise (Boeing Burn Through)

Total Heat Release (OSU-vertical)

Total Heat Release (OSU-horizontal)

Maximum Heat Release Rate (OSU-vertical)

Maximum Heat Release Rate (OSU-horizontal)

Smoke Emission (OSU-vertical)

Smoke Emission (OSU-horizontal)

Total Heat Release (DTA)

Peel Strength

Flatwise Tensile Strength

Impact Strength

Density

STEP 2

Data were tabulated in a convenient form prior to calculations. The tabulations are shown in tables 64-80.

STEP 3

Normalized composite values were calculated for each system; i.e., each of the systems was identified with 17 values, one for each of the parameters listed above (viz., LOI, Peel Strength, Density, etc.). The objective was to obtain a numerical rating between 0 and 1 for each system where 1 represented the best and 0 the worst. This way, the systems could be compared within one test and a composite value representing all tests could subsequently be calculated.

The following equations were employed to calculate the tabulated data in table 87. It can be seen from the equations below that all data within one test (i.e., Peel Strength, Density, etc.) were weighted equally.

$$B_1 = 0.01\,[(FS)(BP)(AD)(C)(F)(AD)(BP)(BP)]^{1/i}$$

where: B_1 = normalized composite LOI

FS = LOI of face sheet

BP = LOI of bond ply

AD = LOI of adhesive

C = LOI of core

F = LOI of foam

i = number of terms in brackets

For example, consider System 5 (see table 64):

$$B_1 = (0.01)\,[(50.7)(32.3)(30.9)(23.0)(32.3)(32.3)]^{1/6}$$

$$B_1 = 0.327$$

$$B_2 = \left\{ \frac{[(20 - S_{NUU})(20 - S_{NUX})(20 - S_{NUZ})(100 - S_{NXU})(100 - S_{NXX})(100 - S_{NXZ})(200 - S_{NZU})(200 - S_{NZX})(200 - S_{NZZ})]}{(6.4 \times 10^{16})} \right\}^{1/9}$$

where: B_2 = normalized composite Smoke Emission (NBS chamber)

S_{NUU} = D_S at 1.0 W/cm^2 (52.9 Btu/ft^2/min) and 1.5 min

S_{NUX} = D_S at 1.0 W/cm^2 (52.9 Btu/ft^2/min) and 4.0 min

S_{NUZ} = maximum D_S at 1.0 W/cm^2 (52.9 Btu/ft^2/min)

S_{NXU} = D_S at 2.5 W/cm^2 (132.2 Btu/ft^2/min) and 1.5 min

S_{NXX} = D_S at 2.5 W/cm^2 (132.2 Btu/ft^2/min) and 4.0 min

S_{NXZ} = maximum D_S at 2.5 W/cm^2 (132.2 Btu/ft^2/min)

S_{NZU} = D_S at 5.0 W/cm^2 (264.3 Btu/ft^2/min) and 1.5 min

S_{NZX} = D_S at 5.0 W/cm^2 (264.3 Btu/ft^2/min) and 4.0 min

S_{NZZ} = maximum D_S at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

For example, consider System 5 (see table 65):

$$B_2 = [(20 - 0.0)(20 - 0.0)(20 - 0.0)(100 - 0.5)(100 - 1.2)$$
$$(100 - 20.6)(200 - 15.3)(200 - 23.9)(200 - 38.4)$$
$$\div (6.4 \times 10^{16})]^{1/9}$$

$$B_2 = 0.928$$

$$B_3 = \left\{ \frac{[(500 - COU)(500 - COX)(500 - COZ)(20 - HCNU)(20 - HCNX)(20 - HCNZ)(20 - XHCN)]}{(2 \times 10^{13})} \right\}^{1/7}$$

where:

B_3 = normalized composite Toxic Gas Emission (NBS chamber)

COU = CO concentration at 1.0 W/cm^2 (52.9 Btu/ft^2/min) and 4.0 min

COX = CO concentration at 2.5 W/cm^2 (132.2 Btu/ft^2/min) and 4.0 min

COZ = CO concentration at 5.0 W/cm^2 (264.3 Btu/ft^2/min) and 4.0 min

HCNU = HCN concentration at 1.0 W/cm^2 (52.9 Btu/ft^2/min) and 4.0 min

HCNX = HCN concentration at 2.5 W/cm^2 (132.2 Btu/ft^2/min) and 4.0 min

HCNZ = HCN concentration at 5.0 W/cm^2 (264.3 Btu/ft^2/min) and 4.0 min

XHCN = HCN concentration at 2.5 W/cm^2 (132.2 Btu/ft^2/min) and 10.0 min

For example, consider System 5 (see table 66):

$$B_3 = [(500 - 81.0)(500 - 120.0)(500 - 403.0)(20 - 1.0)$$
$$(20 - 2.0)(20 - 5.0)(20 - 5.0) \div (2 \times 10^{13})]^{1/7}$$

$$B_3 = 0.668$$

$$B_4 = 1 - \frac{BTT}{800}$$

where:

B_4 = normalized composite Total Heat Release (Boeing Burn Through)

BTT = total heat release

For example, consider System 5 (see table 67):

$$B_4 = 1 - (569.6 \div 800)$$

$$B_4 = 0.288$$

$$B_5 = 1 - \frac{BTR}{10}$$

where:

B_5 = normalized composite Maximum Heat Release Rate (Boeing Burn Through)

BRT = maximum heat release rate

For example, consider System 5 (see table 68):

$$B_5 = 1 - (4.1 \div 10)$$

$$B_5 = 0.590$$

$$B_6 = 1 - \frac{BFT}{500}$$

where:

B_6 = normalized composite Backface Temperature Rise (Boeing Burn Through)

BFT = backface temperature at the end of 4.0 min

For example, consider System 5 (see table 69):

$$B_6 = 1 - (331 \div 500)$$

$$B_6 = 0.338$$

$$B_7 = \left[\frac{(200 - VTU)(600 - VTX)(1500 - VTZ)}{(1.8 \times 10^8)}\right]^{1/3}$$

where: B_7 = normalized composite Total Heat Release (OSU-vertical)

VTU = total heat release at 1.0 W/cm^2 (52.9 Btu/ft^2/min)

VTX = total heat release at 2.5 W/cm^2 (132.2 Btu/ft^2/min)

VTZ = total heat release at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

For example, consider System 5 (see table 70):

$$B_7 = [(200 - 127.6)(600 - 275.5)(1500 - 515.1) \div (1.8 \times 10^8)]^{1/3}$$

$$B_7 = 0.505$$

$$B_8 = \left[\frac{(200 - HTU)(400 - HTX)(1500 - HTZ)}{(1.2 \times 10^8)}\right]^{1/3}$$

where: B_8 = normalized composite Total Heat Release (OSU-horizontal)

HTU = total heat release at 1.0 W/cm^2 (52.9 Btu/ft^2/min)

HTX = total heat release at 2.5 W/cm^2 (132.2 Btu/ft^2/min)

HTZ = total heat release at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

For example, consider System 5 (see table 71):

$$B_8 = [(200 - 129.0)(400 - 217.6)(1500 - 782.8) \div (1.2 \times 10^8)]^{1/3}$$

$$B_8 = 0.426$$

$$B_9 = \left[\frac{(1 - VRU)(5 - VRX)(15 - VRZ)}{75}\right]^{1/3}$$

where:

B_9 = normalized composite Maximum Heat Release Rate (OSU-vertical)

VRU = maximum heat release rate at 1.0 W/cm^2 (52.9 Btu/ft^2/min)

VRX = maximum heat release rate at 2.5 W/cm^2 (132.2 Btu/ft^2/min)

VRZ = maximum heat release rate at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

For example, consider System 5 (see table 72):

$$B_9 = [(1 - 0.5)(5 - 1.0)(15 - 6.4) \div (75)]^{1/3}$$

$$B_9 = 0.612$$

$$B_{10} = \left[\frac{(1 - HRU)(2 - HRX)(10 - HRZ)}{20}\right]^{1/3}$$

where:

B_{10} = normalized composite Maximum Heat Release Rate (OSU-Horizontal)

HRU = maximum heat release rate at 1.0 W/cm^2 (52.9 Btu/ft^2/min)

HRX = maximum heat release rate at 2.5 W/cm^2 (132.2 Btu/ft^2/min)

HRZ = maximum heat release rate at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

For example, consider System 5 (see table 73):

$$B_{10} = [(1 - 0.4)(2 - 1.2)(10 - 4.3) \div (20)]^{1/3}$$

$$B_{10} = 0.515$$

$$B_{11} = \left\{ \frac{[(200 - VSTU)(200 - VSTX)(200 - VSTZ)(20 - VSRU)(20 - VSRX)(20 - VSRZ)]}{(6.4 \times 10^{10})} \right\}^{1/6}$$

where: B_{11} = normalized composite Smoke Emission (OSU-vertical)

VSTU = D_M at 1.0 W/cm^2 (52.9 Btu/ft^2/min)

VSTX = D_M at 2.5 W/cm^2 (132.2 Btu/ft^2/min)

VSTZ = D_M at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

VSRU = $d(D_M)/dt$ at 1.0 W/cm^2 (52.9 Btu/ft^2/min)

VSRX = $d(D_M)/dt$ at 2.5 W/cm^2 (132.2 Btu/ft^2/min)

VSRZ = $d(D_M)/dt$ at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

For example, consider System 5 (see table 74):

$$B_{11} = [(200 - 0.0)(200 - 5.2)(200 - 70.4)(20 - 0.0)(20 - 0.0)(20 - 5.2) \div (6.4 \times 10^{10})]^{1/6}$$

$$B_{11} = 0.881$$

$$B_{12} = \left\{ \frac{[(200 - HSTU)(200 - HSTX)(200 - HSTZ)(20 - HSRU)(20 - HSRX)(20 - HSRZ)]}{(6.4 \times 10^{10})} \right\}^{1/6}$$

where: B_{12} = normalized composite Smoke Emission (OSU-horizontal)

HSTU = D_M at 1.0 W/cm^2 (52.9 Btu/ft^2/min)

HSTX = D_M at 2.5 W/cm^2 (132.2 Btu/ft^2/min)

HSTZ = D_M at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

HSRU = $d(D_M)/dt$ at 1.0 W/cm^2 (52.9 Btu/ft^2/min)

HSRX = $d(D_M)/dt$ at 2.5 W/cm^2 (132.2 Btu/ft^2/min)

HSRZ = $d(D_M)/dt$ at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

For example, consider System 5 (see table 75):

$$B_{12} = [(200 - 0.0)(200 - 10.3)(200 - 50.3)(20 - 0.0)(20 - 0.1)(20 - 2.0) \div (6.4 \times 10^{10})]^{1/6}$$

$$B_{12} = 0.927$$

$$B_{13} = (0.001)[(1000 - DFS)(1000 - DB)(1000 - DA)(1000 - DC)(1000 - DF)(1000 - DA)(1000 - DB)(1000 - DB)]^{1/i}$$

where: B_{13} = normalized composite Total Heat Release (DTA)

DFS = total heat release of face sheet

DB = total heat release of bond ply

DA = total heat release of adhesive

DC = total heat release of core

DF = total heat release of foam

i = number of terms in brackets

For example, consider System 5 (see table 76):

$$B_{13} = (0.001)[(1000 - 141.8)(1000 - 177.4)(1000 - 457.0)(1000 - 584.8)(1000 - 177.4)(1000 - 177.4)]^{1/6}$$

$$B_{13} = 0.690$$

$$B_{14} = \frac{[(PF)(PB)]^{1/2}}{30}$$

where: B_{14} = normalized composite Peel Strength

PF = peel strength of face skin

PB = peel strength of back skin

For example, consider System 5 (see table 77):

$$B_{14} = [(10.7)(11.5)]^{1/2} \div (30)$$

$$B_{14} = 0.370$$

$$B_{15} = \frac{FTS}{50}$$

where: B_{15} = normalized composite Flatwise Tensile Strength

FTS = flatwise tensile strength

For example, consider System 5 (see table 78):

$$B_{15} = (17.7) \div (50)$$

$$B_{15} = 0.354$$

$$B_{16} = \frac{IS}{20}$$

where: B_{16} = normalized composite Impact Strength

IS = impact strength

For example, consider System 5 (see table 79):

$$B_{16} = (8.1) \div (20)$$

$$B_{16} = 0.405$$

$$B_{17} = \left[\frac{(DT)(4 - DD)}{8}\right]^{1/2}$$

where: B_{17} = normalized composite Density

DT = panel thickness

DD = panel density

For example, consider System 5 (see table 80):

$$B_{17} = [(0.691)(4 - 1.74) \div (8)]^{1/2}$$

$$B_{17} = 0.442$$

STEP 4

A total assessment based on the laboratory test data then was determined by combining the values in table 87 for each of the 13 systems. The composite values in table 87 were combined using a weighted distribution shown in table 82.

The following equation was employed to calculate the data in table 88:

$$B_{LT} = [(B_1B_2B_3B_{17})^{10} (A_4A_7A_8A_9A_{10})^6 (A_5)^8 (A_6)^4 (A_{11}A_{12})^5 (A_{13}A_{14}A_{15}A_{16})^2]^{1/100}$$

where: B_{LT} = normalized composite value based on laboratory testing

B_1-B_{17} = values from table 87

For example, consider System 5 (see table 87):

$$B_{LT} = \left\{[(0.327)(0.928)(0.668)(0.442)]^{10}\,[(0.288)(0.505)(0.426)(0.612)(0.515)]^{6}\,(0.590)^{8}\,(0.338)^{4}\,[0.881)(0.927)]^{5}\,[(0.690)(0.370)(0.354)(0.405)]^{2}\right\}^{1/100}$$

$$B_{LT} = 0.528$$

STEP 5

Cost of fabrication and cost of material were tabulated in table 84 for each of the systems. Data are based on System 1 (baseline epoxy); i.e., 1.00 manhour for fabrication, $1.00 for miscellaneous fabrication costs, and $100.00 for materials.

STEP 6

A normalized composite value was calculated for each system representing the total cost of fabrication and materials combined. The equation utilized for this, and a sample calculation, follow. See table 89 for the resultant values.

$$B_{18} = [(1 - \frac{LH}{5})\,(1 - \frac{MMC}{1000})]^{1/4}\,(1 - \frac{MC}{2000})^{1/2}$$

where: B_{18} = normalized composite Material and Fabrication Costs

LH = manhours of labor

MMC = miscellaneous material cost

MC = material cost

For example, consider System 5 (see table 84):

$$B_{18} = [(1 - \frac{1.00}{5}) (1 - \frac{1.60}{1000})]^{1/4} (1 - \frac{197.73}{2000})^{1/2}$$

$$B_{18} = 0.897$$

STEP 7

The final step involves combining the normalized composite value based on laboratory testing (B_{LT}) and the normalized composite material and fabrication costs (B_{18}) and obtaining a total overall assessment of each material system (B_T). Table 90 contains the total overall assessment values.

The following equation was used to obtain the values in table 90, and it reflects a weighting of 85% laboratory testing and 15% cost.

$$B_T = [(B_{LT})^{17} (B_{18})^3]^{1/20}$$

where: B_T = normalized total overall assessment

B_{LT} = normalized composite value based on laboratory testing

B_{18} = normalized composite material and fabrication costs

For example, consider System 5 (see tables 88 and 89):

$$B_T = [(0.528)^{17} (0.897)^3]^{1/20}$$

$$B_T = 0.572$$

APPENDIX C
FOAM EVALUATION

This section describes the evaluation of foams relative to their fire containment capabilities. The candidate materials, test methods, test results, and ranking procedures and conclusions are discussed in the following paragraphs.

C.1 CANDIDATE MATERIALS

The candidate foam materials that were evaluated, along with the applicable supplier, are listed as follows:

1. PQ--Hitco
2. Pyrolyzed ICU--Hitco
3. PI/PU--General Plastics
4. Phenolic--Ciba Geigy

Each of these foams was put into phenolic/polyamide honeycomb core (6.35 mm or 0.25 in. thick, 3.175 mm or 0.125 in. cell, and 48 kg/m^2 or 3 lb/ft^3) and tested with no face sheet material incorporated.

C.2 TEST METHODS

Heat release, smoke release, and thermal conductivity tests were performed on the candidate materials and are described below.

C.2.1 HEAT RELEASE

Heat release characteristics were determined using two apparatuses: (1) OSU Release Rate apparatus and (2) Boeing Burn-Through apparatus. The OSU apparatus was operated at 5.0 W/cm^2 (264.3 Btu/ft^2/min) in a flaming mode while the specimens were in a vertical orientation; the detailed procedure is described in appendix A (sec. A.4). The Burn-Through apparatus was operated at 8-9 W/cm^2 (422.9-475.8 Btu/ft^2/min); the detailed test procedure is described in appendix A (sec. A.7).

C.2.2 SMOKE RELEASE

Smoke emission characteristics were determined using the OSU Release Rate apparatus operated at 5.0 W/cm^2 (264.3 Btu/ft^2/min) in a flaming mode with the specimens in a vertical orientation. The detailed test procedure is described in appendix A (sec. A.4).

C.2.3 THERMAL CONDUCTIVITY

The thermal conductivity characteristics were determined using the Boeing Burn-Through apparatus operated at 8-9 W/cm^2 (422.9-475.8 Btu/ft^2/min). The detailed test procedure is described in appendix A (sec. A.7).

C.3 RESULTS AND DISCUSSION

Discussion of the results will be segmented into the individual tests.

C.3.1 HEAT RELEASE

Tables 91 and 92 contain heat release data relating to the candidate foam materials. The maximum rate of heat release was the least for PQ foam, while it was the greatest for PI/PU. This is consistent for both the OSU and Burn-Through apparatuses. Likewise, the PQ foam releases the least amount of heat while the PI/PU releases the most.

C.3.2 SMOKE RELEASE

Table 91 contains smoke release data relating to the candidate foam materials. PQ foam exhibits both the largest smoke release rate and the largest specific optical density (D_M), followed in order by PI/PU, pyrolyzed ICU, and phenolic. The ranking of the foams was the same for both D_M and $d(D_S)/dt$ as shown by the data.

C.3.3 THERMAL CONDUCTIVITY

Table 93 contains backface temperature rise versus time data relating to the candidate foam materials. The information shows phenolic foam to be the best insulator, followed in order by PQ, PI/PU, and pyrolyzed ICU. The rapid increase in temperature for all foam candidates is attributed to the absence of face sheet prepregs (i.e., the samples consisted of foam in core only).

C.4 RANKING PROCEDURES AND CONCLUSIONS

Two ranking procedures were used and will be discussed separately, followed by the conclusions.

C.4.1 RANKING PROCEDURE NO. 1

This method utilizes a weighted average approach. The procedure has been broken down into a series of steps with a sample calculation.

STEP 1

The test data in tables 91-93 were used in the calculations and consist of:

Total Heat Release (OSU-Vertical)

Maximum Heat Release Rate (OSU-Vertical)

Smoke Emission (OSU-Vertical)

Total Heat Release (Boeing Burn Through)

Maximum Heat Release Rate (Boeing Burn Through)

Backface Temperature Rise (Boeing Burn Through)

STEP 2

Normalized composite values were calculated for each foam; i.e., each of the foams were identified with six values, one for each of the parameters listed above (viz., Heat Release, Smoke Release, etc.). The objective was

to obtain a numerical rating between 0 and 1 for each foam, where 1 represented the best and 0 the worst. This way, the systems could be compared within one test and a composite value representing all tests could subsequently be calculated.

The following equations were employed to calculate the tabulated data in table 94. It can be seen from the equations below that all data within one test were weighted equally.

$$A1 = 1 - \frac{VTZ}{600}$$

where: A1 = normalized composite Total Heat Release (OSU-vertical)

VTZ = total heat release at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

For example, consider PI/PU (see table 91):

$$A1 = 1 - (524.0 \div 600)$$

$$A1 = 0.127$$

$$A2 = 1 - \frac{VRZ}{5}$$

where:

A2 = normalized composite Maximum Heat Release Rate (OSU-Vertical)

VRZ = maximum heat release rate at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

For example, consider PI/PU (see table 91):

$$A2 = 1 - (4.4 \div 5)$$

$$A2 = 0.120$$

$$A3 = 1 - \frac{VSTZ + VSRZ}{50}$$

where: A3 = normalized composite Smoke Emission (OSU-vertical)

VSTZ = D_M at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

VSRZ = $d(D_M)/dt$ at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

For example, consider PI/PU (see table 91):

$$A3 = 1 - [(4.7 + 14.6) \div 50]$$

$$A3 = 0.614$$

$$A4 = 1 - \frac{BTT}{300}$$

where:

A4 = normalized composite Total Heat Release (Boeing Burn Through)

BTT = total heat release

For example, consider PI/PU (see table 92):

$$A4 = 1 - (262.7 \div 300)$$

$$A4 = 0.124$$

$$A5 = 1 - \frac{BTR}{10}$$

where:

A5 = normalized composite Maximum Heat Release Rate (Boeing Burn Through)

BTR = maximum heat release rate

For example, consider PI/PU (see table 92):

$$A5 = 1 - (7.5 \div 10)$$

$$A5 = 0.250$$

$$A6 = \frac{BFR}{200}$$

where:

A6 = normalized composite Backface Temperature Rise (Boeing Burn Through)

BFR = time in seconds to reach 538°C (1000°F)

For example, consider PI/PU (see table 93):

$$A6 = 89.6 \div 200$$

$$A6 = 0.448$$

STEP 3

A total assessment based on the laboratory test data was then determined by combining the values in table 94 for each of the foams. The composite values in table 94 were combined using the following weight distribution:

Total Heat Release (OSU-Vertical)	10%
Maximum Heat Release Rate (OSU-Vertical)	10%
Smoke Emission (OSU-Vertical)	10%
Total Heat Release (Boeing Burn Through)	10%
Maximum Heat Release Rate (Boeing Burn Through)	10%
Backface Temperature Rise (Boeing Burn Through)	50%

The following equation was employed to calculate the data in table 95:

$$ALT = \frac{A1 + A2 + A3 + A4 + A5}{10} + \frac{A6}{2}$$

where: ALT = normalized composite value based on laboratory testing

A1-A6 = values from table 94

For example, consider PI/PU (see table 94):

$$ALT = [(0.127 + 0.120 + 0.614 + 0.124 + 0.250) \div 10] + (0.448 \div 2)$$

$$ALT = 0.348$$

STEP 4

Cost of core and foam is shown in table 96 for each of the foams. Data are based on phenolic foam and core (i.e., 1.00 $\$/ft^2$).

STEP 5

A normalized composite value was calculated for each foam representing the material cost. The equation used for this, and a sample calculation, follow. See table 97 for the resultant values.

$$A7 = 1 - \frac{MC}{2}$$

where: A7 = normalized composite material cost

MC = material cost

For example, consider PI/PU (see table 96):

$$A7 = 1 - (1.63 \div 2)$$

$$A7 = 0.185$$

STEP 6

The final step involves combining the normalized composite value based on laboratory testing (ALT) and the normalized composite material cost (A7) and obtaining a total overall assessment of each foam (AT). Table 98 contains the total overall assessment values.

The following equation was used to obtain the values in table 98, and it reflects a weighting of 92.5% laboratory testing and 7.5% cost.

$$AT = 0.925\ ALT + 0.075\ A7$$

where: AT = normalized total overall assessment

ALT = normalized composite value based on laboratory testing

A7 = normalized composite material cost

For example, consider PI/PU (see tables 95 and 97):

$$AT = (0.925)(0.348) + (0.075)(0.185)$$

$$AT = 0.336$$

C.4.2 RANKING PROCEDURE NO. 2

This method utilizes a weighted geometric mean approach. The precedure is a variation of one reported by E. C. Harrington, Jr. (see ref. 25). The geometric mean approach has the advantage that the higher the value of any factor, the more sharply is its relative importance reduced. An arithmetic approach, such as Procedure No. 1 above, has the disadvantage that a good score for one characteristic can compensate for a low value of another. The method has been broken down into a series of steps with a sample calculation.

STEP 1

The test data in tables 91-93 were used in the calculations and consist of:

Total Heat Release (OSU-Vertical)

Maximum Heat Release Rate (OSU-Vertical)

Smoke Emission (OSU-Vertical)

Total Heat Release (Boeing Burn Through)

Maximum Heat Release Rate (Boeing Burn Through)

Backface Temperature Rise (Boeing Burn Through)

STEP 2

Normalized composite values were calculated for each foam; i.e., each of the foams was identified with six values, one for each of the parameters listed above (viz., Heat Release, Smoke Release, etc.). The objective was

to obtain a numerical rating between 0 and 1 for each foam, where 1 represented the best and 0 the worst. This way, the systems could be compared within one test and a composite value representing all tests could subsequently be calculated.

The following equations were employed to calculate the tabulated data in table 99. It can be seen from the equations below that all data within one test were weighted equally.

$$B1 = 1 - \frac{VTZ}{600}$$

where: B1 = normalized composite Total Heat Release (OSU-vertical)

VTZ = total heat release at 5.0 W/cm^2 (264.3 $Btu/ft^2/min$)

For example, consider PI/PU (see table 91):

$$B1 = 1 - (524.0 \div 600)$$

$$B1 = 0.127$$

$$B2 = 1 - \frac{VRZ}{5}$$

where:

B2 = normalized composite Maximum Heat Release Rate (OSU-vertical)

VRZ = maximum heat release rate at 5.0 W/cm^2 (264.3 $Btu/ft^2/min$)

For example, consider PI/PU (see table 91):

$$B2 = 1 - (4.4 \div 5)$$

$$B2 = 0.120$$

$$B3 = \left[\left(1 - \frac{VSTZ}{25}\right)\left(1 - \frac{VSRZ}{25}\right)\right]^{1/2}$$

where: B3 = normalized composite Smoke Emission (OSU-vertical)

VSTZ = D_M at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

VSRZ = $d(D_M)/dt$ at 5.0 W/cm^2 (264.3 Btu/ft^2/min)

For example, consider PI/PU (see table 91):

$$B3 = \left\{[1 - (4.7 \div 25)][1 - (14.6 \div 25)]\right\}^{1/2}$$

$$B3 = 0.581$$

$$B4 = 1 - \frac{BTT}{300}$$

where:

B4 = normalized composite Total Heat Release (Boeing Burn Through)

BTT = total heat release

For example, consider PI/PU (see table 92):

$$B4 = 1 - (262.7 \div 300)$$

$$B4 = 0.124$$

$$B5 = 1 - \frac{BTR}{10}$$

where:

B5 = normalized composite Maximum Heat Release Rate (Boeing Burn Through)

BTR = maximum heat release rate

For example, consider PI/PU (see table 92):

$$B5 = 1 - (7.5 \div 10)$$

$$B5 = 0.250$$

$$B6 = \frac{BFT}{200}$$

where:

B6 = normalized composite Backface Temperature Rise (Boeing Burn Through)

BFT = time in seconds to reach 538°C (1000°F)

For example, consider PI/PU (see table 93):

$$B6 = 89.6 \div 200$$

$$B6 = 0.448$$

STEP 3

A total assessment based on the laboratory test data was then determined by combining the values in table 99 for each of the foams. The composite values in table 99 were combined using the following weight distribution:

Total Heat Release (OSU-Vertical)	10%
Maximum Heat Release Rate (OSU-Vertical)	10%
Smoke Emission (OSU-Vertical)	10%
Total Heat Release (Boeing Burn Through)	10%
Maximum Heat Release Rate (Boeing Burn Through)	10%
Backface Temperature Rise (Boeing Burn Through)	50%

The following equation was employed to calculate the data in table 100:

$$BLT = [(B1)(B2)(B3)(B4)(B5)(B6)^5]^{1/10}$$

where: BLT = normalized composite value based on laboratory testing

B1-B6 = values from table 99

For example, consider PI/PU (see table 99):

$$BLT = [(0.127)(0.120)(0.581)(0.124)(0.250)(0.448)^5]^{1/10}$$

$$BLT = 0.295$$

STEP 4

Cost of core and foam is shown in table 96 for each of the foams. Data are based on phenolic foam and core (i.e., 1.00 $\$/ft^2$).

STEP 5

A normalized composite value was calculated for each foam representing the material cost. The equation used for this, and a sample calculation, follow. See table 101 for the resultant values.

$$B7 = 1 - \frac{MC}{2}$$

where: B7 = normalized composite material cost

MC = material cost

For example, consider PI/PU (see table 96):

$$B7 = 1 - (1.63 \div 2)$$

$$B7 = 0.185$$

STEP 6

The final step involves combining the normalized composite value based on laboratory testing (BLT) and the normalized composite material cost (B7) and obtaining a total overall assessment of each foam (BT). Table 102 contains the total overall assessment values.

The following equation was used to obtain the values in table 102, and it reflects a weighting of 92.5% laboratory testing and 7.5% cost.

$$BT = [(BLT)^{9.25} (B7)^{0.75}]^{1/10}$$

where: BT = normalized total overall assessment

BLT = normalized composite value based on laboratory testing

B7 = normalized composite material cost

For example, consider PI/PU (see tables 100 and 101):

$$BT = [(0.295)^{9.25} (0.185)^{0.75}]^{1/10}$$

$$BT = 0.285$$

2-2

C.4.3 CONCLUSIONS

Both ranking procedures (viz., sec. C.4.1 and C.4.2) produced the same results. That is, the ranking of the candidate foams was identical in both methods and was as follows:

1. Phenolic
2. PQ
3. Pyrolyzed ICU
4. PI/PU

It was concluded that, for the application desired in this effort, phenolic foam would produce the desired results more effectively than the other three evaluated.

APPENDIX D
MATERIAL SPECIFICATION

This section contains a preliminary material specification for "Fire Resistant, Resin Preimpregnated, Glass Fabric for Interior Sandwich Panels."

1. SCOPE

a. This specification covers the requirements for fire-resistant, resin-impregnated, glass fabrics with low smoke and toxic gas emission characteristics. They are intended for use in the fabrication of interior decorative sandwich panels.

b. This specification requires qualified products.

2. CLASSIFICATION

2.1 TYPES

Properties of the unimpregnated reinforcements for the material types below are shown in table D.1.

Table D.1—Properties of Unimpregnated Reinforcements

Property	Woven Fiberglass	
Product designation	181	120
Type	I	II
Average weight, kg/m^2 (oz/yd^2)	0.281-0.305 (8.30-9.00)	0.098-0.110 (2.89-3.25)
Average thickness, mm (in)	0.203-0.279 (0.008-0.011)	0.102-0.152 (0.004-0.006)
Type of weave	8 Shaft satin	4 Shaft satin
Thread count (Warp) No./cm (No./in.)	22.44-23.23 (57-59)	23.62 (60)
Thread count (Fill), No./cm (No./in)	21.26 (54)	22.83 (58)

Note: The values shown are for materials which have not been impregnated and are not to be used for inspection or engineering requirements.

a. Type I - The preimpregnated material shall consist of Style 181 glass fabric impregnated with a rigid, thermosetting, fire-resistant, modified phenolic resin.

b. Type II - The preimpregnated material shall consist of Style 120 glass fabric impregnated with a rigid, thermosetting, fire-resistant, modified phenolic resin.

2.2 CLASSES

a. Class 1 - A dry, boardy material exhibiting slight adhesive properties when in contact with itself, honeycomb core, or a tooling surface.

b. Class 2 - A drapable material exhibiting definite adhesive properties when in contact with itself, honeycomb core, or a tooling surface.

3. REFERENCES

Except where a specific issue is indicated, the issue of the following references in effect on the date of invitation for bid shall form a part of this specification to the extent indicated herein.

a.	ASTM D695	Compressive Properties of Rigid Plastics
b.	ASTM E162	Surface Flammability of Materials Using a Radiant Heat Energy Source
c.	FAR 25-32	Fire Protection - Compartment Interiors
d.	FTMS No. 406	Plastics, Methods of Testing
e.	MIL-G-55636	Glass Cloth, Resin Preimpregnated (B-Stage)
f.	MIL-STD-401	Sandwich Constructions and Core Materials: General Test Methods

g. NBS Technical Note No. 708 — Interlaboratory Evaluation of Smoke Density Chamber

4. DEFINITIONS

a. Batch - A batch is defined as a continuous impregnation run from a standard or jumbo roll or rolls of the same batch or lot of glass cloth joined together and run through the same resin mix solution.

b. Crease or Wrinkle - A condition of the surface of the material where the nominal thickness is not appreciably changed, but the material is permanently formed into a ridge.

c. Resin-Starved Area - An area with less than normal resin content, sometimes causing delamination or separation between plies due to poor bond.

d. Fold - A condition in which the fibers are laid back over themselves and laminated into the sheet, causing a permanent ridge of increased thickness.

e. Cockling - Longitudinal undulations in the material.

f. Roll - A roll is defined as any section from the above batch furnished as a continuous strip of prepreg, free of joints or seams.

g. Warp - The lengthwise parallel yarns of the fabric reinforcements. The roll direction of the prepreg or machine direction, running parallel to the selvage.

h. Storage Life - The period of time impregnated materials may be stored and retain the properties governed by this specification.

i. Fill - The crosswise yarns running at 90 degrees to the warp of the glass fabric reinforcement.

j. Selvage - The woven ends of the filling yarns that form the fabric edge.

k. Warp Face - That side of the fabric where the bulk of the yarns are parallel to the selvage.

m. Filling Face - That side of the fabric where the bulk of the yarns are perpendicular to the selvage.

n. Work Life - That period during which the prepreg, after removal from storage, remains suitable for its intended use when maintained under ambient work shop conditions.

o. Honeycomb Core Mark-Off or Telegraphing - Hexagonal patterns or lines that are visible on the decorative surface of a sandwich panel, which were not visible on the decorative laminate prior to fabrication into a panel.

5. MATERIAL REQUIREMENTS

5.1 QUALITY

The material shall be uniform in appearance and condition, and free from material detrimental to fabrication, appearance, and performance. No folds, creases, tears, permanent distortions, or resin-starved areas are allowed between the first and last yard of the roll. Cockling or wrinkling in any roll that adversely affects the decorative laminate (Type I only) or sandwich panel shall be considered unacceptable and the remainder of the roll shall be rejected. Backing and/or release media shall part freely from the material without evidence of resin separation from

the glass substrate. The material must make acceptable decorative laminates (Type I only) and/or sandwich panels when fabricated in accordance with the preliminary process specification in appendix E.

5.2 STORAGE LIFE

The storage life of these materials shall be a minimum of 180 days from the date the materials are shipped from the supplier's facilities when maintained at a temperature below -12°C (10°F) during storage and below 7°C (45°F) during shipping.

5.3 WORK LIFE

Prepreg must have a minimum effective room-temperature working life of at least 5 days at 23.9°C (75°F) or below or 1 day at 24.4 to 43.3°C (76 to 110°F).

5.4 PREPREG REQUIREMENTS

5.4.1 DIMENSIONAL TOLERANCES

Variations from the purchase order shall not be greater than ± 2.54 cm (± 1 in.) of the width nor ± 5 percent of the length ordered.

5.4.2 PHYSICAL PROPERTIES

Physical properties of the prepreg shall be within the limits shown in table D.2.

Table D.2—Physical Properties of Prepreg

Property	Type		Test method section
	I	II	
Resin solids content, %	46 ± 3	51 ± 3	9.1
Flow, %	5 - 27	5 - 27	9.3
Gel time, min.	8 ± 4	8 ± 4	9.2
Volatiles, % maximum	1.5	1.5	9.4

5.4.3 COLOR

Unless otherwise specified, the color of the prepreg material shall be natural. Variations in color from batch to batch are acceptable.

5.5 LAMINATE REQUIREMENTS

5.5.1 COMPRESSION AND TENSILE PROPERTIES (TYPE I ONLY)

Fabricate laminate test panels by stacking up 12 plies of the prepreg being tested. The plies shall be parallel laminated. Cure in accordance with sections 8.1.f through 8.1.k. The requirements of table D.3 must be met when tested in accordance with sections 9.5.1, 9.5.2, and 9.5.3.

Table D.3—Laminate Properties (Type I Only)

Property	Requirement
Compression ultimate, 0 degree to warp, R.T., kg/cm^2 (lb/in^2)	3515 (50,000) minimum average
Compression modulus, 0 degree to warp, R.T., kg/cm^2 (lb/in^2)	2.1×10^5 (3.0×10^6) minimum average
Tensile ultimate, 0 degree to warp, R.T., kg/cm^2 (lb/in^2)	3164 (45,000) minimum average
Tensile modulus, 0 degree to warp, R.T., kg/cm^2 (lb/in^2)	2.1×10^5 (3.0×10^6) minimum average

5.6 DECORATIVE LAMINATE REQUIREMENTS (TYPE I ONLY)

5.6.1 BOND STRENGTH

Fabricate a decorative laminate in accordance with Section 8.1. The decorative film shall not peel from the prepreg when tested in accordance with section 9.5.4.

5.7 SANDWICH PANEL REQUIREMENTS

When the material is used to fabricate sandwich panels in accordance with section 8.2, the completed panels shall meet the following requirements.

5.7.1 HONEYCOMB CORE MARK-OFF

The decorative surface of the panel must exhibit no signs of honeycomb core mark-off (telegraphing) when examined visually without aid of magnification.

5.7.2 FLAMMABILITY

Flammability properties of the completed sandwich panels shall be within the limits shown in table D.4.

Table D.4—Flammability Properties of Sandwich Panels

Test	Requirement	Test method
12 seconds, vertical	Average self-extinguishing time, 15 sec. maximum. Average burn length, 20.32 cm (8 in) maximum. Average drip extinguishing time, 5 sec. maximum.	FAR 25-32
60 seconds, vertical	Average self-extinguishing time, 15 sec. maximum. Average burn length, 15.24 cm (6 in) maximum. Average drip extinguishing time, 3 sec. maximum.	FAR 25-32
30 seconds, 45 degrees	Average self-extinguishing time, 15 sec. maximum. Average afterglow, 10 sec. maximum Flame penetration, none.	FAR 25-32
Flame spread index	25 maximum average	ASTM E 162

5.7.3. SMOKE EMISSION

When completed sandwich panels are tested in accordance with appendix II of NBS Technical Note No. 708 utilizing an Aminco NBS smoke chamber at 2.5 W/cm^2 (132.2 Btu/ft^2/min) in a flaming mode, the smoke density (D_S) of each test specimen shall not exceed 50 during the first 4 minutes. (Note: place decorative face toward heat source and test a minimum of three specimens.)

5.7.4 TOXIC GAS EMISSION

When completed sandwich panels are tested in accordance with appendix II of NBS Technical Note No. 708 utilizing an Aminco NBS smoke chamber at 2.5 W/cm^2 (132.2 Btu/ft^2/min) in a flaming mode, Dräger tubes are used to measure toxic gas concentrations. Toxic gas concentration limits are shown in table D.5.

Table D.5—Sandwich Panel Toxic Gas Concentration Requirements

Toxicant	Maximum concentration at 4 min, ppm
CO	3500
HCN	150
HF	50
HCl	500
SO_2	100
NO_x	100

5.7.5 MECHANICAL PROPERTIES

a. Peel Strength

When tested in accordance with section 9.5.5, the panels must produce peel strengths as shown in table D.6.

Table D.6—Peel Requirements

Test condition	Requirement
Honeycomb core to bond ply-face sheet	11.62 cm•kg/7.62 cm width (10 in•lb/3 in width) minimum average.
Bond ply to face sheet	9.22 cm•kg/7.62 cm width (8 in•lb/3 in width) minimum individual.

b. Flatwise Tensile Strength

When tested in accordance with section 9.5.6, the panels shall provide a minimum strength of 10.55 kg/cm^2 (150 $lb/in.^2$).

c. Flexural Strength

When tested in accordance with section 9.5.7, the panels shall provide a stress of 50 kg/cm (280 lb/in.) minimum and a modulus of 1.5×10^5 kg/cm^2 (21.3×10^5 $lb/in.^2$) minimum.

5.8 HANDLEABILITY

When the material is received and at any time within the storage life of the material, it shall have the following characteristics:

a. The Class 1 material must exhibit no adhesive properties when in contact with itself, honeycomb core, or the tooling surface.

b. The Class 2 material must be drapable, exhibiting adhesive properties when in contact with honeycomb core, or a tooling surface that has been prepared for layup. Adhesive properties are defined as the ability of the material to adhere lightly to itself during hand layup to the extent that stripping a ply will not appreciably disturb a previous ply after application of hand pressure.

6. QUALIFICATION

a. All requests for qualification shall be accompanied by data and samples as required.

b. The qualification sample shall consist of one representative production sample roll (at least 45.72 m or 50 yd) for each specific type for which qualification is sought.

c. The qualification sample submitted for approval shall be accompanied by a test report in duplicate which shows that the sample supplied meets the requirements of this specification. All suppliers shall either have test facilities required to test in accordance with this specification, or shall utilize the services of an approved commercial laboratory to accomplish such tests. The adequacy of test facilities may be verified, as deemed necessary, by a survey of such facilities.

d. Qualification testing shall consist of a demonstration of the conformance of the sample, supplied in accordance with Section 6.b, to all the requirements of this specification and a report indicating acceptance or rejection of the material with respect to its in-process handling characteristics. If the material is rejected for handling, specific reasons for rejecting the material must be noted.

e. This specification requires approved supplier listing in the Qualified Products List Supplement to this specification for preimpregnated materials. No changes in raw materials or methods of manufacture shall be made without notification

and prior approval in writing. Requalification of the revised material may be required and a revised supplier designation may be requested.

7. QUALITY CONTROL

Preimpregnated materials controlled by this specification are subject to inspection to assure conformance to this specification.

7.1 SUPPLIER QUALITY CONTROL

a. The supplier shall obtain a 91.44-cm (36-in.) swatch from the beginning of the roll and from the end of the roll, as shown in figure D.1. The following tests shall be performed on both samples and the data shall be submitted with the roll.

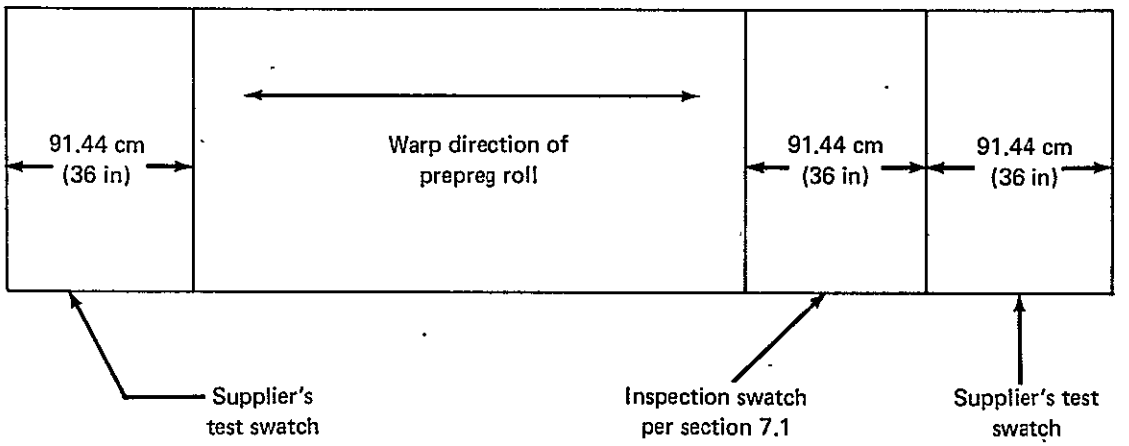


Figure D.1—Test Swatch Location

Resin Solids Content - Test in accordance with section 9.1

Gel Time - Test in accordance with section 9.2

Percent Flow - Test in accordance with section 9.3

Percent Volatiles - Test in accordance with section 9.4

Flammability Properties - Test in accordance with section 5.7.2 (60-second vertical only)

If there is more than one roll of prepreg in a production batch, the value from the supplier's test sample at the end of one roll is considered to be the same as the beginning of the succeeding roll.

b. Each production shipment of a qualified product shall be accompanied by a test report or reports giving the actual test data (individual test specimen values as well as averages) obtained from each individual production batch when tested according to section 7.1.a. The test report or reports shall provide evidence that material of each production shipment satisfies the requirements of this specification.

c. A referee test sample from each roll shall be retained at the supplier's plant. In the event that material is rejected by the purchaser, gel time and percent flow tests shall be run on the referee sample. Referee samples may be discarded after the storage requirements of section 5.2 have been attained or after the purchaser has accepted the material.

7.2 PURCHASER QUALITY CONTROL

a. The following test shall be run on each batch of material and will include a representative sampling of rolls to assure conformance to this specification.

Flammability Properties - Test in accordance with section 5.7.2 (60-second vertical only)

b. Purchaser Quality Control shall review all supplier test reports and shall perform additional testing, if necessary, to assure that the material meets the specification requirements.

8. FABRICATION OF TEST PANELS

8.1 DECORATIVE LAMINATE

The lamination and texturing of Type I shall be accomplished in a positive pressure press as follows:

a. One layer of canvas texturing medium shall be placed on the caul plate that is to be placed on the lower platen. (Caution: Assure that canvas surface is free of dirt and lint of any type.)

b. Place a screen-printed Tedlar composite, or integrally colored Tedlar, front face down, on the texturing canvas.

c. Once the Tedlar is placed on the texturing canvas, place one ply of Type I on the back side of the Tedlar. (Caution: Make certain the prepreg is at least 5.08 cm or 2 in. from the edge of the Tedlar, otherwise the flash from the prepreg may contaminate the canvas or decorative surface.)

d. Place two layers of release paper over the prepreg, making certain it extends at least 5.08 cm (2 in.) beyond the prepreg edge.

e. Position a caul plate, the same size as that which is to be placed on the lower platen, over the layup and make certain the edges of each are aligned.

f. Load the press and set the pressure controller to apply 7.03 kg/cm^2 (100 $lb/in.^2$) to the laminate stack.

g. Close the press and apply the pressure to the laminate stack. A pressure "overshoot" of up to 1.76 kg/cm^2 (25 $lb/in.^2$) is acceptable; however, in no case shall the pressure on the laminates exceed 8.79 kg/cm^2 (125 $lb/in.^2$). During cure, a pressure drop of 1.76 kg/cm^2 (25 $lb/in.^2$) below the 7.03 kg/cm^2 (100 $lb/in.^2$) pressure controller set point is acceptable; however, in no case shall the pressure on the laminate drop below 5.27 kg/cm^2 (75 $lb/in.^2$).

h. Heat the press to 154 $\pm$ 6°C (310 $\pm$ 10°F).

i. Start the cure when layup temperature has reached a minimum of 149°C (300°F). Cure cycle is 20 $\pm$ 1 minutes at 154 $\pm$ 6°C (310 $\pm$ 10°F) and 7.03 $\pm$ 1.76 kg/cm^2 (100 $\pm$ 25 $lb/in.^2$) gauge pressure.

j. After cure, maintain pressure and cool the press to 38°C (100°F) or less.

k. Release pressure and remove the laminate stack.

8.2 SANDWICH PANEL

a. Fabricate the sandwich panel according to the construction shown in figure D.2. The Type I prepreg shall be oriented so that the "filling face" of the fabric is facing the core and the warp of the fabric is perpendicular to the core ribbon direction.

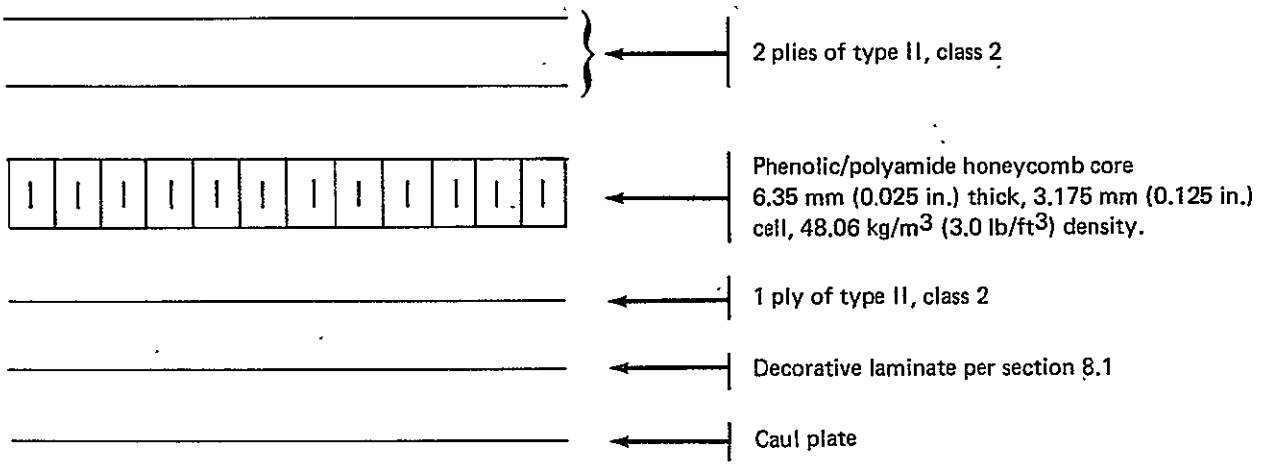


Figure D.2—Sandwich Panel Configuration

b. Panels shall be cured for a minimum of 1 hour at 132 ± 6°C (270 ± 10°F) under a vacuum pressure of 50.8 cm-Hg (20 in.-Hg) minimum. One layer of release film (100SG30TR-Tedlar release film--pricked on 9.525-mm or 0.375-in. centers, or equivalent) and bleeder (unbleached Osnaburg cloth, Federal Specification CCC-C-429, or equivalent) shall be placed over the bag face of the test panel. The release film and bleeder shall be in direct contact with the vacuum line.

9. MATERIAL TEST METHODS

9.1 RESIN SOLIDS CONTENT

a. Remove a 91.44-cm (36-in.) swatch of prepreg material from the roll (see fig. D.1). A minimum of three 10.16- x 10.16-cm (4- x 4-in.) specimens must be obtained from the 91.44-cm (36-in.) swatch and must be taken in a pattern that will be representative of the swatch. The specimens taken from the edge must be at least 5.08 cm (2 in.) from the selvage. (Note: The prepreg shall be allowed to attain room temperature prior to sampling.)

b. Remove polyethylene backing from the resin content specimens and place in an air-circulating oven at 121 $\pm$ 3°C (250 $\pm$ 5°F) for 10 minutes $\pm$ 5 seconds, then remove from the oven. Cool in a desiccator and immediately weigh to the nearest 10 milligrams. The specimens must then be placed in a muffle furnace at 566 $\pm$ 28°C (1050 $\pm$ 50°F) until the resin is completely burned away (evidenced by the appearance of white glass cloth with no dark areas). The burnout product shall be weighed and the weight recorded.

$$\text{Percent Resin Solids Content} = \frac{WA - B}{WA} \times 100$$

where:

WA = weight of devolatilized specimen before burnout

B = weight of specimen after burnout

9.2 GEL TIME

a. Cut a sufficient number of 5.08- x 5.08-cm (2- x 2-in.) specimens, taken at intervals to be representative of the entire swatch (prepared in accordance with sec. 7.1.a), to make a laminate of approximately 20 gm (0.7 oz) weight.

b. Remove the polyethylene film from the specimens prepared in accordance with section 9.2.a and carefully stack the specimens. Place the stack between 0.076-mm (0.003-in.) aluminum foil.

c. Place the specimen between the heated platens of a press regulated at a temperature of 121 ± 3°C (250 ± 5°F), as indicated by a thermocouple and potentiometer or pyrometer. The specimen should be placed a minimum of 2.54 cm (1 in.) from the edge of the platen. Platen opening shall be a minimum to permit the application of pressure as soon as possible.

d. Upon insertion of the specimen, sufficient pressure must be applied to create a bead of resin around the edge of the panel. The stopwatch must be started as soon as pressure is applied. The resin bead must be probed with a wood or glass rod until the specimen has gelled. Gelling will be preceded by the appearance of "stringiness" (i.e., long strands of resin drawn out from the bead when probed) followed by the disappearance of these strands upon gelation. Gelation is the point where no stringing of the resin is noticed and the probed material has a rubbery feel. At this point, the

specimen must be removed from the press and inspected. If the material is hard and brittle while still hot, the gel point has been exceeded. If the specimen is soft, tacky, and stringy when probed while still hot, the gel point has not quite been achieved.

9.3 RESIN FLOW

Resin flow shall be determined in accordance with MIL-G-55636, except that the specimens shall be cured 10 ± 0.25 minutes at 121 ± 3°C (250 ± 5°F) under 3.5 ± 0.4 kg/cm^2 (50 ± 5 lb/in.^{2}) pressure. Two determinations shall be made.

9.4 VOLATILES

a. Two specimens 10.16 x 10.16 cm (4 x 4 in.) shall be prepared from the test swatch of section 9.1.a. Cut a small slot in or near the center of each specimen. The specimens shall be identified by roll number and specimen number.

b. Remove the polyethylene backing from each specimen, then weigh the specimen to the nearest milligram. Suspend the specimen by a hole near its center from an "S"-shaped hook. The specimens then shall be hung in an air-circulating oven regulated at 121 ± 3°C (250 ± 5°F). Place a sheet of aluminum foil below the specimen to catch any resin runoff that might occur. (Note: The hook and aluminum foil must be weighed before and after test to get an accurate result.)

c. The oven door shall be closed and a stopwatch started (the oven door shall not be open for more than 10 seconds). After 10 minutes ± 5 seconds, the specimen shall be removed

and placed in a desiccator to cool. The specimen then shall be weighed to the nearest milligram.

$$\text{Percent Volatile Content} = \frac{WM - WN}{WM} \times 100$$

where:

WM = weight of constituents prior to test

WN = weight of constituents after test

9.5 MECHANICAL PROPERTIES

9.5.1 TENSILE PROPERTIES

Ultimate tensile strength and modulus of elasticity parallel to the warp shall be determined in accordance with FTMS No. 406, Test Method 1011, Type II, except that the rate of travel of the crosshead must be 1.27 mm/min (0.05 in./min) until the initial straight-line portion of the stress-strain curve is obtained for modulus calculation. The extensometer then shall be removed and the rate of travel of the crosshead increased to 5.08-6.35 mm/min (0.20-0.25 in./min) until failure occurs.

9.5.2 COMPRESSION STRENGTH

Compression strength shall be determined, parallel to the warp, in accordance with ASTM D695.

9.5.3 MODULUS COMPRESSION

The compression modulus shall be determined parallel to the warp. Tests shall be accomplished in accordance with ASTM D695.

9.5.4 TEDLAR PEEL

Slit the decorative film surface of the laminate with a sharp

knife. Attempt to peel the decorative film from the Type I material.

9.5.5 SANDWICH PANEL PEEL

a. Determine the peel strength of the sandwich panels by (1) peeling the decorative laminate side of the panel from the core and (2) peeling the Type I decorative laminate from the Type II bond ply.

b. Test in accordance with the Climbing Drum method outlined in MIL-STD-401. Specimen size shall be 7.62 x 30.48 cm (3 x 12 in.) with the 30.48-cm (12-in.) dimension parallel to fabric warp direction, and head speed shall be 2.54 cm/min (1 in./min). Obtain a peel curve and compute the average peel strength for each specimen. For each type of peel in section 9.5.5.a, test a minimum of five specimens. Report individual and average test results.

9.5.6 FLATWISE TENSILE STRENGTH

Determine flatwise tensile strength in accordance with MIL-STD-401. Specimen size shall be 5.08 x 5.08 cm (2 x 2 in.). For each material, test a minimum of five specimens. Report individual and average test results.

9.5.7 FLEXURAL STRENGTH

Determine the compression strength of the sandwich panel by testing according to MIL-STD-401. Test specimens are 7.62 x 60.96 cm (3 x 24 in.) with the 60.96-cm (24-in.) dimension parallel to the core ribbon direction of the panel. Any values from specimens that fail at or under the load points or by core shear,

adhesion, or tension are not included in the calculations. Figure D.3 shows the test apparatus schematic. The compressive stress is determined on the specimens through the following calculation:

$$S_c = \frac{Pd}{2w\left(C_T + \frac{t_t + t_c}{2}\right)}$$

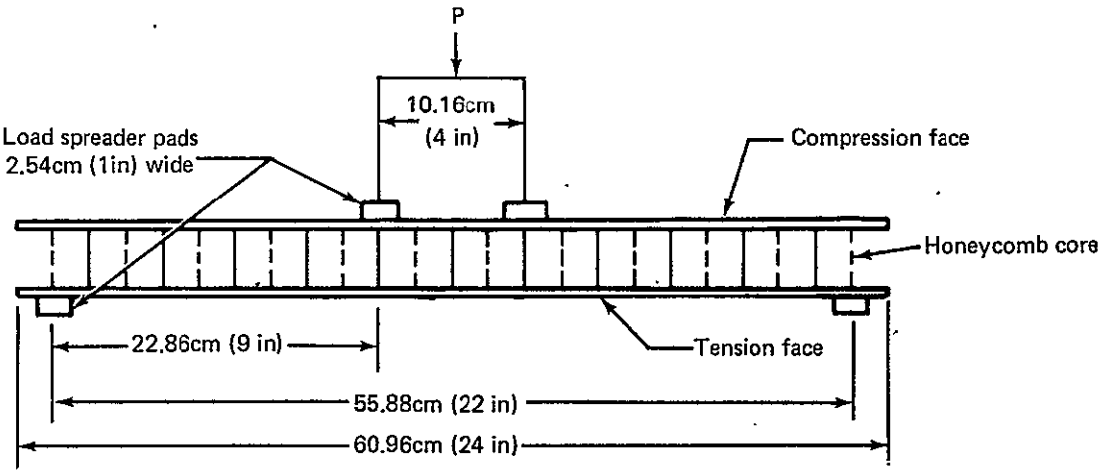


Figure D.3—Beam Flexure Test Setup

where:

S_c = compressive stress, kg/cm (lb/in.)

P = failure load, kg (lb)

d = distance from support post to load post, 22.86 cm (9 in.)

w = specimen width, 7.62 cm (3 in.)

t_c = compression face thickness, 0.03937 cm (0.0155 in.)

t_t = tensile face thickness, 0.02286 cm (0.0090 in.)

C_T = core thickness, 6.35 mm (0.25 in.)

Modulus is determined on the specimens through the following calculation:

$$M = \frac{P}{Y} \cdot \frac{d(3L^2 - 4d^2)}{48w\left(\frac{t_c t_t}{t_c + t_t}\right)\left(h - \frac{t_c + t_t}{2}\right)^2}$$

where:

M = modulus, kg/cm^2 ($lb/in.^2$)

P/Y = slope of initial portion of load-deflection curve, kg/cm (lb/in.)

d = distance from support post to load post, 22.86 cm (9 in.)

L = span between support posts, 55.88 cm (22 in.)

w = specimen width, 7.62 cm (3 in.)

t_c = compression face thickness, 0.03937 cm (0.0155 in.)

t_t = tensile face thickness, 0.02286 cm (0.0090 in.)

h = total sandwich panel thickness, 6.767 mm (0.2664 in.)

10. MATERIAL IDENTIFICATION

Each packaged roll and roll of prepreg shall be permanently and legibly marked to give the following information:

a. Resin System and Glass Fabric Reinforcement

b. Batch Number

c. Roll Number

d. Purchase Order Number

e. Quantity and Width

f. Manufacturer

g. Manufacturer's Number

h. Date of Impregnation

i. Resin Content and Gel Time

j. Flow and Volatiles

In addition, each packaged roll must contain in red letters, at least 5.08 cm (2 in.) high, the following information:

"DURING SHIPMENT, MAINTAIN BELOW 7°C (45°F),
STORE BELOW -12°C (10°F), DO NOT STAND ON END"

11. PACKAGING AND MARKING

a. Packaging shall be accomplished in such a manner as to assure delivery of the material and to retain the properties required by this specification. Each roll shall be stored in a horizontal position and be entirely supported by its core. Rolls should never be stored in an upright manner.

b. Each roll shall be permanently and legibly marked on the inside edge of the core by a batch and lot number and should contain a maximum of 47.6 kg (105 lb) of prepreg, unless otherwise specified.

c. All prepreg material shall contain a layer of polyethylene backing or equivalent, with at least 2.54 cm (1 in.) of excess on each edge. The roll shall be sealed in a polyethylene bag.

APPENDIX E
PROCESS SPECIFICATION

This section contains a preliminary process specification for "Fire Resistant, Resin Preimpregnated, Glass Fabric Faced Honeycomb, Interior Sandwich Panels."

1. SCOPE

This specification establishes the requirements for the manufacture of interior sandwich panels using component materials that evolve low smoke and toxic gases when exposed to flame.

2. REFERENCES.

Except where a specific issue is indicated, the current issue of the following references shall be considered a part of this specification to the extent indicated herein.

a.	ASTM C297	Tension Test of Flat Sandwich Construction in Flatwise Plane
b.	ASTM C393	Flexure Test of Flat Sandwich Constructions
c.	ASTM D638	Test for Tensile Properties of Plastics
d.	ASTM D695	Compressive Properties of Rigid Plastics
e.	ASTM D1781	Climbing Drum Peel Test for Adhesives
f.	FAR 25-32	Fire Protection-Compartment Interiors
g.	FTMS No. 406	Plastics, Methods of Testing
h.	MIL-STD-401	Military Standard Sandwich Constructions and Core Materials; General Test Methods

3. MATERIALS CONTROL

3.1 PRODUCTION MATERIALS

The following materials are incorporated into the product during fabrication.

	Material	Source	Storage Requirement
a.	Phenolic Prepreg - Type I, Class 1	Appendix D	See Note 1
b.	Phenolic Prepreg - Type II, Class 2	Appendix D	See Note 1
c.	Acrylic Screen Printing Ink	K.C. Coatings, Inc. 500 Railroad Ave. North Kansas City, Mo. 64116	See Note 2
d.	0.051 mm (0.002 in.) White Tedlar	E.I. DuPont 5500 Union Pacific Ave. Los Angeles, Ca 90022	See Note 3
e.	0.025 mm (0.001 in.) Clear Tedlar + DuPont 6880 Adhesive	E.I. DuPont 5500 Union Pacific Ave. Los Angeles, Ca 90022	See Note 3

	Material	Source	Storage Requirement
f.	Phenolic/Polyamide Honeycomb Core, 3.175 mm (0.125 in.) Cell, 48.06 kg/m^3 (3.0 lb/ft^3) Density	Hexcel Corp. Casa Grande, Ariz. 85222 Ciba Geigy Corp. Orbitex Products Department 3550 NW 49th St. Miami, Fl 33142	See Note 3

Note 1: The storage life of this material at or below -12°C (10°F) is 180 days from the date of receival. Material held beyond 180 days shall be retested to the requirements of the applicable specification and shall have the desired Exposure Unit Capability verified before use. The Exposure Unit Capability is 200 units. These units are accumulated as follows:

One unit per hour when held between -12°C (10°F) and 24°C (75°F)

Three units per hour when held between 24°C (76°F) and 38°C (100°F)

These units are additive and begin to accumulate from the day the prepreg is removed from storage. Prepregs that have accumulated 200 units shall be discarded.

Note 2: The ink shall not deteriorate when stored for 12 months at 21 $\pm$ 11°C (70 $\pm$ 20°F) in an unopened container.

Note 3: Noncontaminating area and at ambient temperature. If storage conditions are supplied by the vendor, they must be followed.

3.2 NONPRODUCTION MATERIALS

The following materials are not incorporated into the product, but are typical of those used for a specific purpose. Other materials may be substituted for those listed below provided they satisfactorily perform the same function.

	Material	Source	Storage Requirement
a.	Release Paper, Noncontaminating	Open	See Note 1
b.	Embossing Media (Silicone Blanket, Fabric Blanket, or Metal Plate)	Open	See Note 1
c.	Vacuum Bag Materials		
	(1) Polyvinyl Alcohol Film - 0.076 mm (0.003 in.) maximum	Reynolds Company Grottoes, Virginia	See Note 1
	(2) Nylon Film - 0.076 mm (0.003 in.) maximum	Open	See Note 1
	(3) Mylar Film	E.I. DuPont 4455 Fruitland Ave. Los Angeles, Ca	See Note 1

	Material	Source	Storage Requirement
d.	Solvents		
	(1) Acetone, Federal Specification O-A-51	Open	See Specification
	(2) Methyl Ethyl Ketone, Federal Specification TT-M-261	Open	See Specification
	(3) Methyl Isobutyl Ketone, TT-M-268	Open	See Specification
	(4) Toluene, TT-T-548 or JAN-T-171	Open	See Specification
	(5) Aliphatic Naphtha, TT-N-95	Open	See Specification
e.	Osnaburg Cloth (unbleached) Federal Specification CCC-C-429, any Class	Open	See Note 1
f.	Porous Polyester Paper		
	(1) Reemay, Spunbonded Polyester, Style 2024	E.I. DuPont Textile Fibers Department Wilmington, Delaware	See Note 1
	(2) Mochburg, S01850	West Coast Paper Company 2203 - 1st Ave. S Seattle, Wa	See Note 1

Note 1: Noncontaminating area and at ambient temperature. If storage conditions are supplied by the vendor, they must be followed.

4. FACILITIES CONTROL

4.1 NIP ROLL LAMINATOR

This specification is to be used with the Nip Roll Laminator (Litzler Company drawing no. EA-2775), or equivalent, possessing a temperature range from 149°C (300°F) to 204°C (400°F) and that is capable of maintaining a temperature, within ± 6°C (± 10°F) of the set temperature, across the surface of the roll. The unit must be equipped with a static eliminator and vacuum brush combination to remove static charge and loose surface particles from the film. The location of this eliminator brush combination should be above the web expander roll. A second static elminator and vacuum brush is required to eliminate static and loose particles from the panel before they enter the laminating (Nip) rolls.

5. ENVIRONMENTAL CONTROL

Manufacturing shall be done in a room kept under positive pressure with filtered air and with a floor made of nondusting, nonflaking, easily cleaned materials. Area shall be kept clean and free of dust. The relative humidity shall be 40 to 60 percent.

6. FABRICATION OF DECORATIVE LAMINATES

6.1 PROCESS FLOW CHARTS

Figures E.1 and E.2 are flow charts showing the fabrication process of a Decorative Film Laminate and a Decorative Film/Prepreg Laminate.

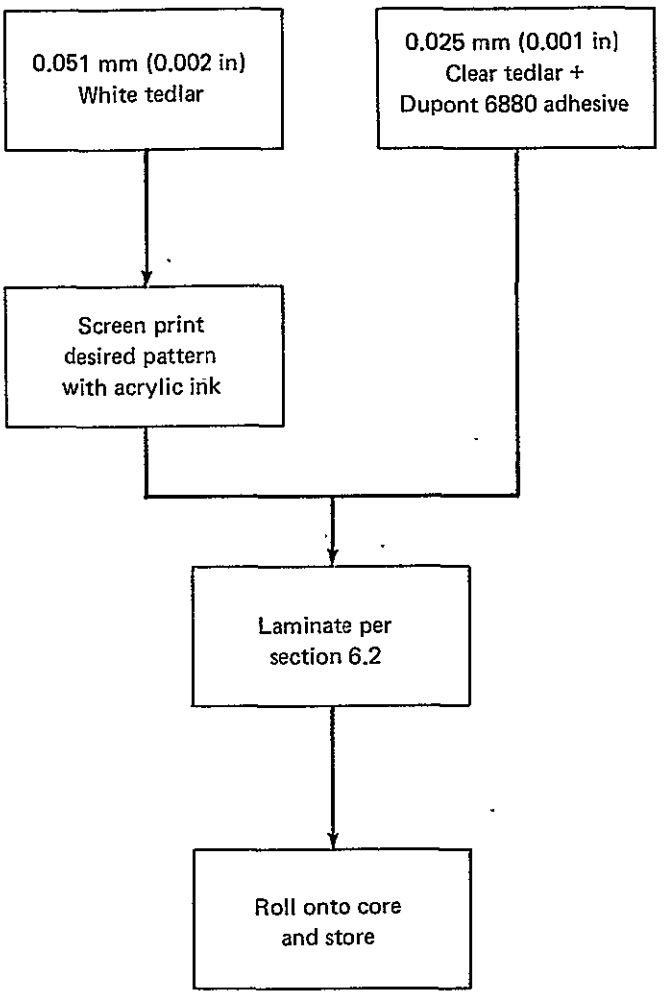


Figure E.1—Fabrication of Decorative Film Laminates

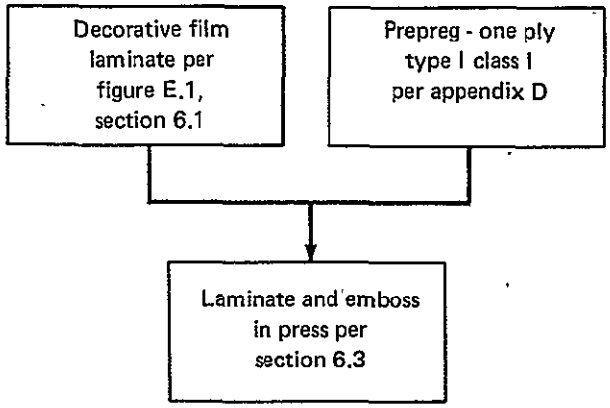


Figure E.2–Fabrication of Decorative Film/Prepreg Laminates

6.2 LAMINATING OF TOP CLEAR FILM AND SCREEN PRINTED SUBSTRATE FILM

a. Materials

(1) 0.025-mm (0.001-in.) clear Tedlar + DuPont 6880 adhesive

(2) 0.051-mm (0.002-in.) white Tedlar screen printed

b. Equipment

Nip Roll Laminator

c. Laminating Procedure

(1) Feed the films into the Tedlar laminator with the adhesive side of the clear Tedlar contacting the silk-screened design. Align the films and lower the nip roll. (Note: The film widths and alignment are such that the clear Tedlar extends completely over the silk-screened area but not over the edge of the substrate film.)

(2) Wind the laminate onto the core.

6.3 FABRICATION OF DECORATIVE FILM/PREPREG LAMINATES IN POSITIVE PRESSURE PRESS

a. Material

(1) Decorative film laminate shown in figure E.2, section 6.1

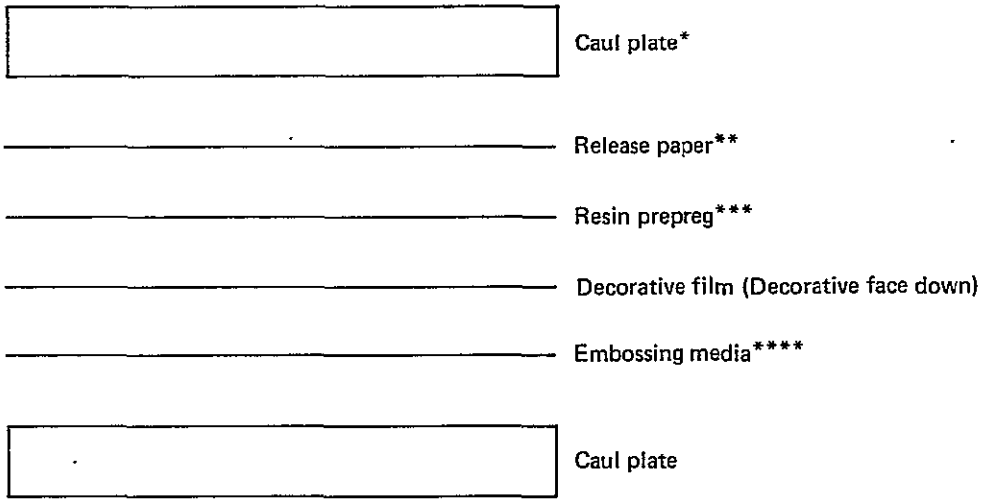
(2) Prepreg, one ply, shown in figure E.2, section 6.1

b. Equipment

Positive pressure press--multiple opening

c. Procedure

(1) Lay up materials on caul plate as shown in figure E.3.



* The top caul plate shall be of the same size as the bottom caul plate.
** The release paper shall extend at least 5.08 cm (2 in) beyond the edges of the resin prepreg.
*** Make certain the resin prepreg is at least 5.08 cm (2 in) from the edge of the decorative film, otherwise the flash from the resin may contaminate the embossing medium or the decorative film.
**** Use the embossing medium to produce the desired texture. Assure that the embossing medium is free of dirt and lint.

Figure E.3—Layup for Decorative Film/Embossing Resin Laminate

(2) Place the laminate from section 6.3.c(1) into the press and set the pressure controller to apply 7 kg/cm^2 (100

lb/in.^{2}) to the assembly.

(3) Close press and apply pressure. A pressure "overshoot" of up to 1.8 kg/cm^2 (25 lb/in.^{2}) is acceptable; however, in no case shall the pressure on laminate exceed 8.8 kg/cm^2 (125 lb/in.^{2}). During cure, a pressure drop of 1.8 kg/cm^2 (25 lb/in.^{2}) below the pressure controller set point is acceptable; however, in no case shall the pressure on the laminate drop below 5.3 kg/cm^2 (75 lb/in.^{2}).

(4) Heat the press to 154 $\pm$ 8°C (310 $\pm$ 15°F).

(5) Start timing the cure when the layup temperature has reached a minimum of 146°C (295°F). Cure for 20-30 minutes.

(6) After cure, maintain pressure and cool press to 38°C (100°F) or less.

(7) Release pressure and remove the laminate assembly.

(8) Remove all release papers from the laminate.

7. FABRICATION OF SANDWICH PANELS

7.1 PREPARATION OF MATERIALS PRIOR TO FABRICATION

7.1.1 HONEYCOMB CORE

a. Cleaning

(1) Wash locally contaminated areas with acetone, MEK, or naphtha.

(2) If core is totally contaminated, immerse in acetone or MEK bath for 60 seconds. If necessary, immerse for an additional 60 seconds. A maximum of three immersions

is permitted.

(3) The core shall be completely free of solvent and accumulated dust prior to use.

7.1.2 PREPREGS

a. To prevent moisture condensation, allow prepreg taken from refrigerated storage to warm to room temperature in the unopened container or polyethylene bag prior to use.

b. Prior to use, prepregs shall meet the storage requirements shown in section 3.1.

7.1.3 DECORATIVE LAMINATE FROM SECTION 6.3

Clean decorative face and back side of laminate with a clean cloth dampened with MEK or acetone.

7.2 PROCESS FLOW CHARTS

Figure E.4 is a flow chart showing the fabrication process of a sandwich panel.

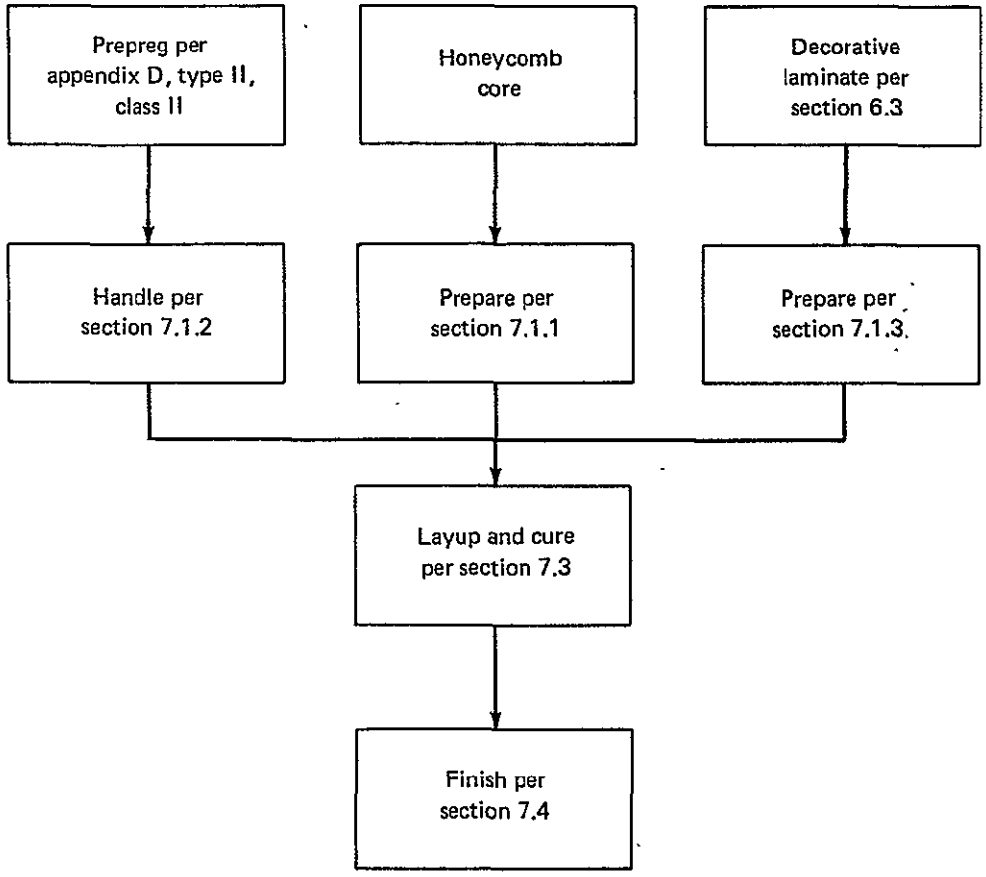


Figure E.4--Sandwich Panel Flow Chart

7.3 LAYUP AND CURE PROCEDURE

7.3.1 LAYUP

Lay up the materials of construction and aid materials as shown in figure E.5.

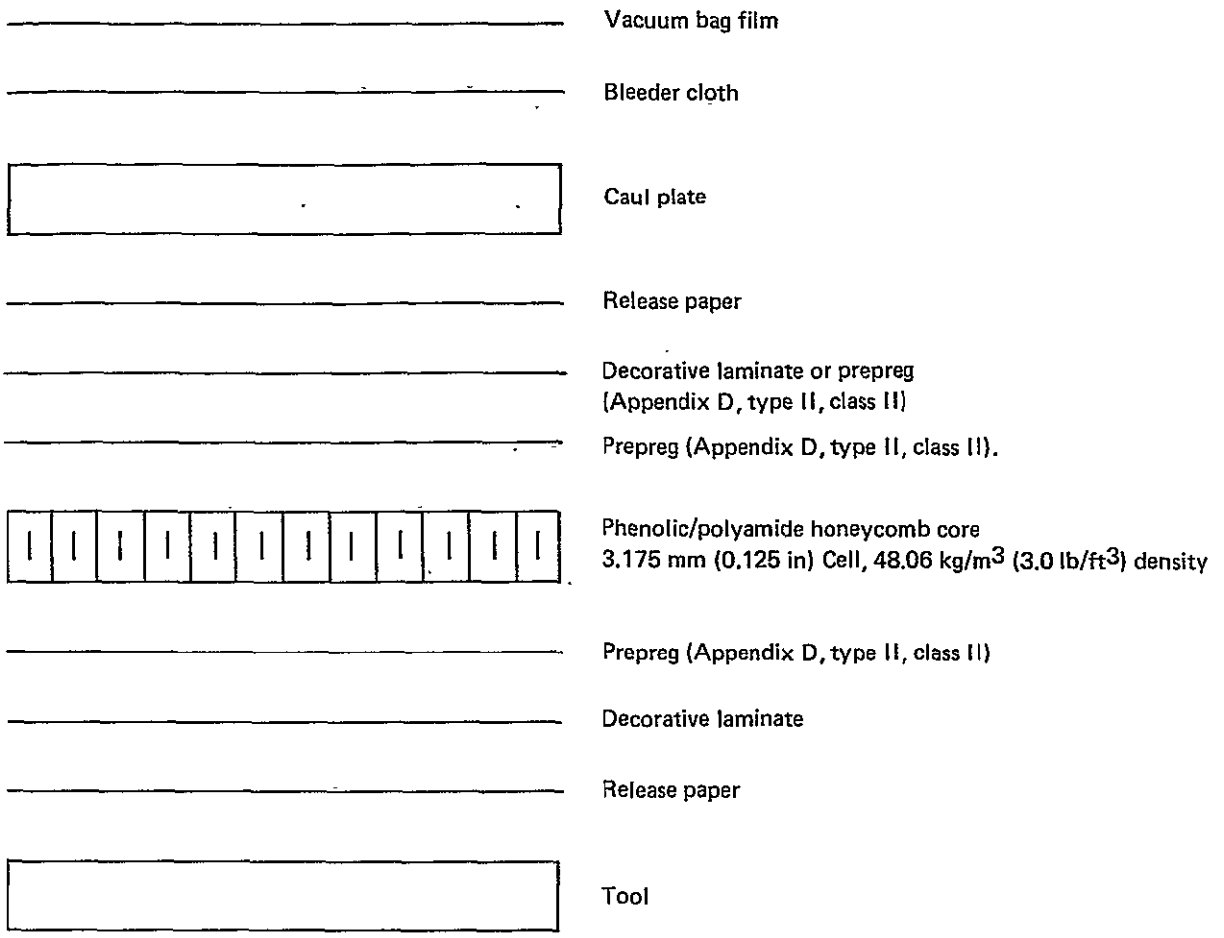


Figure E.5—Sandwich Panel Layup

a. Place release paper on tool surface.

b. Position the cleaned decorative laminate, with the decorative face down, against the release paper.

c. Place prepreg on back side of the decorative laminate. Sweep out all wrinkles and air pockets.

d. Position honeycomb core on prepreg.

e. Place prepreg on top of the core. Smooth out all wrinkles and air pockets.

f. Position the second decorative laminate or prepreg on the prepreg.

g. Place release paper over the entire panel.

h. Cover with bleeder cloth (e.g., osnaburg, canvas, etc.). The bleeder cloth should extend around the periphery of the tool surface layup area and extend to the vacuum ports or vacuum tubular ring.

i. Cover entire assembly with polyvinyl alcohol (PVA), nylon, or other bagging material and seal to the tool surface beyond the vacuum ports or perforated rings with bag sealing compound to form a vacuum film envelope.

j. Apply vacuum slowly to a minimum of 50.8 cm-Hg (20 in.-Hg). Smooth out wrinkles in critical areas. Check for leaks.

7.3.2 CURING AND DEBAGGING

a. Place in oven and heat to 132 ± 6°C (270 ± 10°F) and hold for a minimum of 1 hour at that temperature.

b. Remove from oven and allow to cool below 49°C (120°F) before releasing vacuum.

c. Ground the tool to safely discharge the static electricity and de-bag assembly.

7.4 FINISHING

Trim and sand or rout as required.

8. QUALITY CONTROL

8.1 MATERIALS CONTROL

a. Verify that materials incorporated into the part during

fabrication comply with the applicable specifications and sources listed in section 3.

b. Verify that storage and handling of materials are in accordance with requirements listed in section 3.

8.2 PROCESS CONTROL

a. Verify that materials preparation and component requirements are in accordance with applicable specifications.

b. Verify that part fabrication is accomplished in accordance with sections 6 and 7.

8.3 COMPLETED PARTS INSPECTION

Verify that there are no quality imperfections that exceed acceptable limits as listed in table E.1.

a fairly constant rate of about 3.5% during the past 25 years. This implies that the level of activity in the transportation sector depends very much on factors like GNP, population, GNP per capita, etc. These factors, socio-economic in nature, have been discussed in great detail in Section 1 of this chapter. As past historical data have indicated, when the GNP is high, so is the transportation activity, and vice-versa.

The transportation modal distribution, on the other hand, depends on factors such as energy intensiveness, mode flexibility, energy supply, societal environmental concern, etc. Theoretically, when the price of gasoline rises society will tend to favor more use of public transit. Conversely, when the supply of fuel is abundant and its price is low, society will, in turn, favor modes of transportation that can offer more convenience and comfort - in other words, speedier and private means of transportation, which are more energy intensive.

Another major factor that greatly influences the intensity of transportation and its model distribution, especially for the future, is technological advancement. As available energy resources are used up, future growth in transportation activities will be constrained unless new means of propulsion systems or new types of fuels are provided.

Table E.1—Part Acceptance Criteria

Imperfection	Acceptable limits	
	Decorative surface	Non-decorative surface
Surface imperfections	Unacceptable	Acceptable as is if imperfection does not penetrate into glass reinforcement
Punctures	Unacceptable	Unacceptable
Delaminations	Unacceptable	Unacceptable
Wrinkles	Unacceptable	Acceptable provided wrinkles do not exceed 6.35 mm (0.25 in) in width or 2.54 mm (0.10 in) in height
Core to skin separation	Unacceptable	Unacceptable
Damaged honeycomb core	Unacceptable	Unacceptable
Warpage	Shall not exceed 0.021 mm/cm (0.025 in/ft) except parts installed with all edges supported shall conform to support structure with a force not exceeding 2.98 kg/m (2 lb/ft) of panel edge.	Shall not exceed 0.021 mm/cm (0.025 in/ft) except parts installed with all edges supported shall conform to support structure with a force not exceeding 2.98 kg/m (2 lb/ft) of panel edge.

REFERENCES

1. NPRM 75-3, "Smoke Emission from Compartment Interior Materials," Federal Register, Volume 40, No. 30, February 12, 1975.
2. ANPRM 74-38, "Compartment Interior Materials Toxic Gas Emission," Federal Register, Volume 39, No. 251, December 30, 1974.
3. NASA-TMX-58141, "Full Scale Aircraft Cabin Flammability Test of Improved Fire Resistant Materials," Stuckey, R. N. Supkis, D. E., and Price, L. J., June 1974.
4. NASA-TMX-58172, "Full Scale Aircraft Cabin Flammability Test of Improved Fire Resistant Materials - Test Series II," Stuckey, R. N., Supkis, D. E., Bricker, R. W., and Kumenecz, J. F., April 1976.
5. Kourtides, D. A., Parker, J. A., and Gilwee, W. J., "Thermochemical Characterization of Aircraft Interior Materials," Journal of Fire and Flammability, Vol. 6, July 1975, pp. 373-391.
6. Parker, J. A., Kourtides, D. A., Fish, R. H., and Gilwee, W. J., "Fire Dynamics of Modern Aircraft from a Materials Point of View," Journal of Fire and Flammability, Vol. 6, October 1975, pp. 534-553.
7. Kourtides, D. A., Parker, J. A., Hilado, C. J., Anderson, R. A., Tustin, E. A., Arnold, D. B., Gaume, J. G., Binding, A. T., and Mikeska, J. L., "Fire Safety Evaluation of Aircraft Lavatory and Cargo Compartments," Journal of Fire and Flammability, Vol. 7, January 1976, pp. 125-159.
8. Kourtides, D. A., Parker, J. A., Leon, H. A., Williamson, R. B., Hasegawa, H., Fisher, F., Draemel, R., Marcussen, W. H., and Hilado, C. J., "Fire Containment Tests of Aircraft Interior Panels," Journal of Fire and Flammability, Vol. 7, April 1976, pp. 257-278.

9. Kourtides, D. A., Parker, J. A., Gilwee, W. J., Lerner, N. R., Hilado, C. J., LaBossiere, L. A., and Hsu, M. S., "Flammability Characteristics of Aircraft Interior Composites," Journal of Fire and Flammability, Vol. 7, July 1976, pp. 401-426.

10. Kourtides, D. A., Parker, J. A., and Hilado, C. J., "Thermochemical Characterization of Some Thermoplastic Materials," Journal of Fire and Flammability, Vol. 8, January 1977, pp. 59-94.

11. Hilado, C. J., Barnes, G. J., Kourtides, D. A., and Parker, J. A., "The Use of the High Flux Heater in the Smoke Chamber to Measure Ignitability and Smoke Evolution of Composite Panels," Journal of Fire and Flammability, Vol. 8, July 1977, pp. 324-331.

12. Anderson, R. A. and Johnson, G. A., "Aircraft Interior Sandwich Panel Development," Journal of Fire and Flammability, Vol. 8, July 1977, pp. 364-381.

13. NAS2-8700, Modification 1, "Development of Aircraft Lavatory Compartments with Improved Fire Resistance Characteristics," NASA-ARC Contract.

14. Federal Aviation Regulation, Part 25, Amendment 25-32, Paragraph 25-853, "Fire Protection - Compartment Interiors," effective date May 1, 1972.

15. ASTM D2863, "Flammability of Plastics Using the Oxygen Index Method."

16. NAS2-9153, "Development of Assembly Techniques for Fire Resistant Aircraft Interior Panels," NASA-ARC Contract.

17. NBS Technical Note 708, "Interlaboratory Evaluation of Smoke Density Chamber," T. G. Lee, 1971.

18. ASTM D1781, "Climbing Drum Peel Test for Adhesives."

19. ASTM D903, "Peel or Stripping Strength of Adhesive Bonds."

20. MIL-STD-401, "Military Standard Sandwich Constructions and Core Materials; General Test Methods."

21. Federal Test Method Standard (FTMS) No. 191, Method 5304.1, "Abrasion Resistance of Cloth; Oscillatory Cylinder (Wyzenbeek) Method."

22. Federal Test Method Standard (FTMS) No. 406, Method 1091, "Abrasion Wear (Loss in Weight)."

23. ASTM D412, "Tension Testing of Vulcanized Rubber."

24. Federal Test Method Standard (FTMS) No. 191, Method 5660.2, "Colorfastness to Light of Textile Materials; Accelerated Method."

25. Harrington, Jr., Edwin C., Industrial Quality Control, April 1965.

Table1.—Flammability Test Matrix

Test	Screening Task 1	Sandwich Panel Development, Task 2	Decorative Film Development, Task 3	Decorative Laminate Development, Task 4	Combined Sandwich Panel, Task 5
Limiting oxygen index * (LOI)	—	x	x	—	—
Flammability					
(60 sec. IGN., FAR 25-32)	x	—	x	—	—
Smoke emission					
NBS chamber					
1.0 W/cm^2 (52.9 Btu/ft^2/min)	x	x	x	—	x
1.7 W/cm^2 (89.9 Btu/ft^2/min)	x	—	—	—	—
2.5 W/cm^2 (132.2 Btu/ft^2/min)	x	x	x	-	x
5.0 W/cm^2 (264.3 Btu/ft^2/min)	—	x	x	—	x
OSU release rate apparatus					
1.0 W/cm^2 (52.9 Btu/ft^2/min)	—	x	—	—	x
2.5 W/cm^2 (132.2 Btu/ft^2/min)	—	x	—	—	x
5.0 W/cm^2 (264.3 Btu/ft^2/min)	—	x	—	—	x
Toxic gas emission					
NBS chamber					
1.0 W/cm^2 (52.9 Btu/ft^2/min)	x	x	x	—	x
1.7 W/cm^2 (89.9 Btu/ft^2/min)	x	—	—	—	—
2.5 W/cm^2 (132.2 Btu/ft^2/min)	x	x	x	—	x
5.0 W/cm^2 (264.3 Btu/ft^2/min)	—	x	x	—	x
Pyrolysis Tube* - 600^{o}C (1112^{o}F)					
Quartz tube	x	—	x	—	—
Monel tube	—	—	x	—	—
Heat release					
OSU release rate apparatus					
1.0 W/cm^2 (52.9 Btu/ft^2/min)	—	x	—	—	x
2.5 W/cm^2 (132.2 Btu/ft^2/min)	—	x	—	—	x
5.0 W/cm^2 (264.3 Btu/ft^2/min)	—	x	—	—	x
Flame penetration					
Boeing burn through	—	x	—	—	x
Animal exposure chamber					
NASA — ARC	—	x	x	—	—

*Run on constituents separately (i.e., face skins, adhesives, etc.)

Table 2.—Thermophysical Test Matrix

Test	Screening Task 1	Sandwich Panel Development, Task 2	Decorative Film Development, Task 3	Decorative Laminate Development, Task 4	Combined Sandwich Panel, Task 5
Differential thermal analysis in air at 10C°/min (18F°/min)	—	x	—	—	—
Thermogravimetric analysis in air at 10C°/min (18F°/min)	—	x	—	—	—

Note: All tests run on constituents separately (i.e., face skins, adhesives, etc.)

Table 3.—Mechanical Test Matrix

Test	Screening Task 1	Sandwich Panel Development, Task 2	Decorative Film Development, Task 3	Decorative Laminate Development, Task 4	Combined Sandwich Panel, Task 5
Peel strength	x	x	x	x	x
Flexure	x	—	—	—	x
Flatwise tension	—	x	—	—	x
Abrasion	—	—	—	x	x
Elongation	—	—	x	—	—
Impact strength	—	x	—	—	—

Table 4.—Additional Test Matrix

Test	Screening Task 1	Sandwich Panel Development, Task 2	Decorative Film Development, Task 3	Decorative Laminate Development, Task 4	Combined Sandwich Panel, Task 5
Density	—	x	—	—	—
Stain resistance	—	—	x	—	—
Ultraviolet stability	—	—	x	—	—
Decorative capability	—	—	—	x	—

Table 5.—Materials Matrix — Task 1

SYST. NO.	DECORATIVE FILM	FACESHEET		BOND PLY AND BACK SKIN		HONEYCOMB CORE	
A	PVF*/ACRYLIC INK/PVF**	EPOXY	FIBERITE MXB-7203	EPOXY	DUPONT CORLAR 5131	PHENOLIC/ POLYAMIDE	3PCF NOMEX
B	PVF*/ACRYLIC INK/PVF**	PHENOLIC	NARMCO 8250	PHENOLIC	NARMCO 9250	PHENOLIC/ POLYAMIDE	3PCF NOMEX
C	PVF*/ACRYLIC INK/PVF**	PHENOLIC	NARMCO 8250	PHENOLIC	NARMCO 8250	PHENOLIC/ POLYAMIDE	3PCF NOMEX
D	PVF*/ACRYLIC INK/PVF**	PHENOLIC	FIBERITE MXB-6070	PHENOLIC	FIBERITE MXB-6070	PHENOLIC/ POLYAMIDE	3PCF NOMEX
E	PVF*/ACRYLIC INK/PVF**	PHENOLIC	DUPONT CORLAR 6113-1	PHENOLIC	DUPONT CORLAR 6113-1	PHENOLIC/ POLYAMIDE	3PCF NOMEX
F	PVF*/ACRYLIC INK/PVF**	PHENOLIC	CIBA-GEIGY FIBREDUX 428	PHENOLIC	CIBA-GEIGY FIBREDUX 428	PHENOLIC/ POLYAMIDE	3PCF NOMEX

* 0.025 mm (0.001in.) PVF TOP FILM
** 0.051 mm (0.002in.) PVF SUBSTRATE FILM

Table 6.—Materials Matrix — Task 2

SYST. NO.	FACESHEET		BOND PLY AND BACK SKIN		ADHESIVE		HONEYCOMB CORE		FOAM	
1	EPOXY	FIBERITE MXB-7203	EPOXY	FIBERITE MXB-7251		NONE	PHENOLIC/ POLYAMIDE	3PCF NOMEX	NONE	
2	PHENOLIC	NARMCO 8250	PHENOLIC	NARMCO 9251		NONE	PHENOLIC/ POLYAMIDE	3PCF NOMEX	NONE	
3	BISMALEIMIDE	HEXCEL 531	BISMALEIMIDE	HEXCEL 532		NONE	PHENOLIC/ POLYAMIDE	3PCF NOMEX	NONE	
4	POLYIMIDE	DUPONT PYRALIN 3002	POLYIMIDE	DUPONT PYRALIN 3002	POLYIMIDE	AM.CYANAMID BR-34	POLYIMIDE/ FIBERGLASS	4.5 PCF	NONE	
5	PHENOLIC	NARMCO 8250	PHENOLIC	NARMCO 9251		NONE	PHENOLIC/ POLYAMIDE	3PCF NOMEX	ICU	2PCF
6	POLYIMIDE	DUPONT PYRALIN 3002	POLYIMIDE	DUPONT PYRALIN 3002	POLYIMIDE	AM.CYANAMID BR-34	POLYIMIDE/ FIBERGLASS	4.5PCF	PI/PU	2PCF
7	BISMALEIMIDE	RHODIA KERIMID 601	BISMALEIMIDE	RHODIA KERIMID 601	POLYIMIDE	AM.CYANAMID FM-34	PHENOLIC/ POLYAMIDE	1.8PCF NOMEX	PQ	2PCF
8	POLYIMIDE	DUPONT PYRALIN 3002	POLYIMIDE	DUPONT PYRALIN 3002	POLYIMIDE	AM.CYANAMID BR-34	POLYIMIDE/ POLYAMIDE	3.0 PCF PI-NOMEX	NONE	
9	POLYIMIDE	DUPONT PYRALIN 3002	POLYIMIDE	DUPONT PYRALIN 3002	POLYIMIDE	AM.CYANAMID BR-34	POLYIMIDE/ POLYAMIDE	3.0 PCF PI-NOMEX	PI/PU	2PCF
10	PHENOLIC	CIBA-GEIGY FIBREDUX 917G	PHENOLIC	CIBA-GEIGY FIBREDUX 917G		NONE	PHENOLIC/ POLYAMIDE	3.0 PCF NOMEX	NONE	
11	PHENOLIC	FIBERITE MXB-6070	PHENOLIC	FIBERITE MXB-7255		NONE	PHENOLIC/ POLYAMIDE	3.0 PCF NOMEX	ICU	2PCF
12	PHENOLIC	FIBERITE MXB-6070	PHENOLIC	FIBERITE MXB-7255		NONE	PHENOLIC/ POLYAMIDE	3.0 PCF NOMEX	NONE	
13	BISMALEIMIDE	RHODIA KERIMID 601	BISMALEIMIDE	RHODIA KERIMID 601	POLYIMIDE	AM.CYANAMID FM-34	PHENOLIC/ POLYAMIDE	1.8 PCF NOMEX	ICU (PYROLYZED)	2PCF

Table 7.— Materials Matrix — Task 3

Film no.	Top film	Substrate film
1	0.025mm (0.001in) PVF	0.051mm (0.002in) PVF
2	0.025mm (0.001in) PVF	0.025mm (0.001in) FM-PVF
3	0.038mm (0.0015in) PVF_2	0.051mm (0.002in) PVF_2
4	0.025mm (0.001in) PVF	0.127mm (0.005in) PC
5	0.025mm (0.001in) PVF	0.127mm (0.005in) PES

Note: All films contain an acrylic ink layer between the top and substrate films.

Table 8.—Materials Matrix — Task 4

System number	Facesheet		Adhesive		Decorative film
A-1	EPOXY	FIBERITE MXB-7203	NONE		PVF/ACRYLIC INK/PVF*
A-2	PHENOLIC	CIBA-GEIGY FIBREDUX 917G	NONE		PVF/ACRYLIC INK/PVF*
A-3	PHENOLIC	FIBERITE MXB-6070	NONE		PVF/ACRYLIC INK/PVF*
A-4	PHENOLIC	NARMCO 8250	NONE		PVF/ACRYLIC INK/PVF*
A-5	POLYIMIDE	DUPONT PYRALIN 3002	POLYESTER	TF-252	PVF/ACRYLIC INK/PVF*
B-1	EPOXY	FIBERITE MXB-7203	ACRYLIC	DUPONT 6880	PVF/ACRYLIC INK/PC**
B-2	PHENOLIC	CIBA-GEIGY FIBREDUX 917G	ACRYLIC	DUPONT 6880	PVF/ACRYLIC INK/PC**
B-3	PHENOLIC	FIBERITE MXB-6070	ACRYLIC	DUPONT 6880	PVF/ACRYLIC INK/PC**
B-4	PHENOLIC	NARMCO 8250	ACRYLIC	DUPONT 6880	PVF/ACRYLIC INK/PC**
B-5	POLYIMIDE	DUPONT PYRALIN 3002	POLYESTER	TF-252	PVF/ACRYLIC INK/PC**

* 0.025mm (0.001in) PVF TOP FILM AND 0.051mm (0.002in) PVF SUBSTRATE FILM
**0.025mm (0.001in) PVF TOP FILM AND 0.051mm (0.002in) PC SUBSTRATE FILM

Table 9.—Smoke Emission as Measured in the NBS Smoke Chamber — Task 1

System number	Incident heat flux, W/cm^2 (Btu/ft^2/min)	Specific optical density			Time-to reach D_M (corr.), min
		D_S @ 1.5 min	D_S @ 4.0 min	D_M (corr.)	
A	1.0 (52.9)	11.8	17.1	18.4	3.0
	1.7 (89.9)	42.0	45.5	45.5	4.0
	2.5 (132.2)	57.6	57.5	18.4	10.0
B	1.0 (52.9)	1.8	2.7	4.5	20.0
	1.7 (89.9)	4.0	6.8	8.3	15.0
	2.5 (132.2)	10.5	15.5	19.4	10.0
C	1.0 (52.9)	1.6	2.0	2.7	15.0
	1.7 (89.9)	2.7	4.2	6.2	15.0
	2.5 (132.2)	12.7	15.9	17.0	7.0
D	1.0 (52.9)	1.5	2.0	3.1	20.0
	1.7 (89.9)	4.4	4.6	4.7	10.0
	2.5 (132.2)	11.7	13.9	16.1	10.0
E	1.0 (52.9)	2.7	4.1	6.0	15.0
	1.7 (89.9)	6.7	8.4	11.0	15.0
	2.5 (132.2)	16.7	20.7	22.8	10.0
F	1.0 (52.9)	1.6	2.4	3.0	10.0
	1.7 (89.9)	3.5	4.2	4.7	10.0
	2.5 (132.2)	13.3	16.6	17.3	10.0

Table 10.—Peel Strength — Task 1

System number	Peel strength, cm•kg/7.62 cm Width (in•lb/3 in. Width)	
	Face skin	Back skin
A	12.8 (11.1)	17.7 (15.4)
B	2.8 (2.4)	8.9 (7.7)
C	3.3 (2.9)	4.8 (4.2)
D	5.4 (4.7)	5.4 (4.7)
E	— (—)	— (—)
F	1.4 (1.2)	1.7 (1.5)

Table 11.—Beam Flexure — Task 1

System number	Stress, kg/cm Width (lb/in Width)	
	Face side in compression	Back side in compression
A	35.4 (198.5)	38.9 (218.0)
B	27.7 (155.2)	67.8 (379.9)
C	22.7 (126.9)	43.3 (242.3)
D	49.5 (277.1)	39.9 (223.2)
E	— (—)	33.0 (184.9)
F	8.9 (49.7)	10.4 (58.1)

Table 12.—Toxic Gas Emission as Measured in the NBS Smoke Chamber — Task 1

System number	Incident heat flux, W/cm^2 ($Btu/ft^2/min$)	Concentration @ 4.0 min., ppm			
		HF	HCl	HCN	CO
A	1.0 (52.9)	50	10	Trace	100
	1.7 (89.9)	100	16	Trace	200
	2.5 (132.2)	100	120	Trace	100
B	1.0 (52.9)	60	6	Trace	100
	1.7 (89.9)	90	8	Trace	500
	2.5 (132.2)	40	10	Trace	100
C	1.0 (52.9)	60	8	0	100
	1.7 (89.9)	60	12	Trace	100
	2.5 (132.2)	40	12	0	100
D	1.0 (52.9)	100	14	0	50
	1.7 (89.9)	50	8	Trace	100
	2.5 (132.2)	30	12	Trace	100
E	1.0 (52.9)	100	10	Trace	100
	1.7 (89.9)	30	6	Trace	50
	2.5 (132.2)	60	16	Trace	100
F	1.0 (52.9)	40	12	Trace	75
	1.7 (89.9)	100	15	Trace	100
	2.5 (132.2)	150	40	Trace	100

Table 13.—Pyrolysis Tube Decomposition — Task 1

System number	Concentration, mg/gm		
	HCN	HCl	HF
A	11.6	46.0	3.5
B	4.5	1.2	2.9
C	5.1	30.0	3.2
D	3.4	6.8	3.0
E	6.0	2.3	3.4
F	8.2	37.0	3.8

Note: Pyrolysis at 600°C (1112°F)

Table 14.—FAA Flammability — Vertical, 60 sec. —Task 1

System number	Extinguishing time, sec.	Burn length, cm (in)
A	0.8	5.6 (2.2)
B	0.8	4.6 (1.8)
C	0.9	4.8 (1.9)
D	0.9	4.1 (1.6)
E	0.9	5.3 (2.1)
F	0.9	6.1 (2.4)

Table 15.—Limiting Oxygen Index – Task 2

System number	Material	LOI, $\%O_2$
	FACE SHEET	
1	FIBERITE MXB-7203	29.0
2&5	NARMCO 8250	50.7
3	HEXCEL 531	33.9
4,6,8,&9	DUPONT PYRALIN 3002	*
7&13	RHODIA KERIMID 601	56.0
10	CIBA-GEIGY FIBREDUX 917G	*
11&12	FIBERITE MXB-6070	65.8
	BOND PLY	
1	FIBERITE MXB-7251	27.7
2&5	NARMCO 9251	32.3
3	HEXCEL 532	24.6
4,6,8,&9	DUPONT PYRALIN 3002	71.4
7&13	RHODIA KERIMID 601	52.6
10	CIBA-GEIGY FIBREDUX 917G	53.5
11&12	FIBERITE MXB-7255	23.0
	ADHESIVE	
4,6,8,&9	BR-34 (AMERICAN CYANAMID)	49.8
7&13	FM-34 (AMERICAN CYANAMID)	58.9
	FOAM	
5&11	ICU (UPJOHN CPR-9545, 2.3 PCF)	23.0
6&9	PI/PU (GENERAL PLASTICS LAST-A-FOAM FR-15017-2)	27.7
13	PYROLYZED ICU	63.5
	CORE	
1,2,3,5 10,11,&12	PHENOLIC/POLYAMIDE (0.125 in CELL, 3PCF)	30.9
4&6	POLYIMIDE/FIBERGLASS (0.1875 in CELL, 4.5PCF)	58.9
8&9	POLYIMIDE/POLYAMIDE (0.125 in CELL, 3PCF)	35.2

*Does not burn in 100% oxygen

Table 16.—Smoke Emission as Measured in the NBS Smoke Chamber — Task 2

System number	Incident heat flux, W/cm^2 (Btu/ft^2/min)	Specific optical density			Time to reach D_M (corr.), min
		D_S @ 1 5 min	D_S @ 4.0 min	D_M (corr.)	
1	1.0 (52.9)	7 2	9.3	12 1	10 0
	2.5 (132.2)	58.4	62.8	79.9	20 0
	5.0 (264.3)	94.7	96.5	164.0	10 0
2	1.0 (52.9)	0.0	0.0	0 0	0.0
	2.5 (132.2)	1.3	2 1	5.4	15.0
	5.0 (264.3)	6.4	10.1	12.5	10 0
3	1.0 (52.9)	0 0	0 3	5.2	20 0
	2.5 (132.2)	7.1	19.5	64.7	15 0
	5.0 (264.3)	15 9	34.4	85 6	12.0
4	1.0 (52.9)	0.0	0.0	0.0	0 0
	2 5 (132.2)	0 1	0 3	1.5	20.0
	5.0 (264.3)	0.1	0.5	1.1	10 0
5	1.0 (52.9)	0.0	0.0	0 0	0 0
	2.5 (132.2)	0 5	1.2	20 6	20 0
	5.0 (264.3)	15.3	23.9	38 4	15.0
6	1.0 (52.9)	—	—	—	—
	2.5 (132.2)	12 0	32 0	36 4	10.0
	5.0 (264.3)	9 3	28.7	35.7	15.0
7	1.0 (52.9)	0.8	1.2	3 3	20.0
	2.5 (132 2)	8.8	11.2	12 0	7.0
	5.0 (264.3)	14.4	15 8	14.8	4.0
8	1.0 (52.9)	0.0	0.0	0.0	0.0
	2.5 (132.2)	0.3	0.6	2.9	20.0
	5.0 (264.3)	1.7	4 6	6.8	10 0
9	1.0 (52.9)	—	—	—	—
	2 5 (132 2)	8 8	20 5	24.6	20.0
	5.0 (264.3)	8.4	19.9	35.9	10.0
10	1.0 (52.9)	0 6	0.8	0.7	20.0
	2.5 (132.2)	1.7	2 5	1.3	20.0
	5.0 (264.3)	4.5	8.4	10 9	20.0
11	1.0 (52.9)	0.1	0.2	0.6	20 0
	2.5 (132.2)	3 4	4.7	12.4	20 0
	5 0 (264.3)	22.0	34 4	44.1	10.0
12	1.0 (52.9)	0.0	0.0	0 0	0.0
	2.5 (132 2)	0 8	1.0	6.2	20 0
	5.0 (264 3)	6.6	16 3	52.5	15.0
13	1.0 (52.9)	1.2	1.7	2 5	20.0
	2 5 (132 2)	8.6	11.2	10.5	10.0
	5 0 (264.3)	21.8	24.4	22.4	4 0

Table 17.—Smoke Emission as Measured in the OSU Release Rate Apparatus — Vertical Flaming — Task 2

System number	Incident heat flux, W/cm^2 (Btu/ft^2/min)	Maximum smoke release rate, d(DS)/dt		Specific optical density	
		sec $^{-1}$	Time, sec.	Maximum	Time,sec.
1	1.0 (52.9)	0.4	19.3	8.7	58.3
	2.5 (132.2)	6.4	22.3	103.1	149.0
	5.0 (264.3)	16.0	9.7	179.1	252.3
2	1.0 (52.9)	0 0	1.0	0.0	1.0
	2.5 (132.2)	0 0	42.0	1.6	126.7
	5.0 (264.3)	0.9	24.7	24.2	537 3
3	1.0 (52.9)	0.0	1.0	0.0	1.0
	2.5 (132.2)	0.3	28.7	17.5	586.0
	5.0 (264.3)	1.7	13.0	83.1	298.7
4	1.0 (52.9)	0.0	1.0	0.0	1.0
	2.5 (132.2)	0.0	1 0	0.0	1.0
	5.0 (264.3)	0.0	18.3	1.3	112.0
5	1.0 (52.9)	0.0	1.0	0.0	1.0
	2.5 (132.2)	0.0	59.3	5.2	141.3
	5 0 (264.3)	5.2	24.0	70.4	203.3
6	1.0 (52.9)	—	—	—	—
	2.5 (132 2)	0.0	38.0	2.4	193.0
	5.0 (264.3)	0.9	26.3	18.4	104.0
7	1.0 (52.9)	0.0	25.3	1.2	45.7
	2.5 (132.2)	0.1	25.3	3.9	62.0
	5.0 (264.3)	2.7	11.7	29.2	64.7
8	1.0 (52.9)	0.0	1.0	0.0	1.0
	2.5 (132.2)	0.0	1.0	0.0	1.0
	5.0 (264.3)	0.3	51.7	9.2	122.3
9	1.0 (52.9)	—	—	—	—
	2 5 (132.2)	0.0	30.3	2 0	108.7
	5.0 (264.3)	2.4	23.7	41.4	56.3
10	1.0 (52.9)	0.0	1.0	0.0	1.0
	2.5 (132.2)	0.0	7.3	0.4	33.3
	5.0 (264.3)	0.4	21.7	11.1	71.0
11	1.0 (52.9)	0.0	35.3	0.7	80.7
	2.5 (132.2)	0.4	26.7	9.9	91.0
	5.0 (264.3)	8.4	14.7	112.2	404.7
12	1.0 (52.9)	0.0	5.7	0.1	12.0
	2.5 (132.2)	0.0	27.0	5.3	112.0
	5.0 (264.3)	2.4	15.0	56.5	293.0
13	1.0 (52.9)	0.0	27.3	1.7	60.3
	2.5 (132.2)	0.3	23.7	6.2	58.7
	5.0 (264.3)	5.7	12.7	65.3	171.7

Table 18.—Smoke Emission as Measured in the OSU Release Rate Apparatus — Horizontal Flaming — Task 2

System number	Incident heat flux, W/cm^2 (Btu/ft^2/min)	Maximum smoke release rate, d(DS)/dt		Specific optical density	
		sec.$^{-1}$	Time, sec.	Maximum	Time, sec
1	1 0 (52.9)	0.1	17.7	2.6	40.0
	2.5 (132.2)	1.9	22.5	65.8	129.5
	5.0 (264.3)	12.6	20.3	191.5	341.3
2	1 0 (52.9)	0.0	1.0	0.0	1.0
	2.5 (132.2)	0.0	1.0	0.0	1.0
	5.0 (264.3)	1 0	39 0	44.7	402.3
3	1.0 (52.9)	0.0	1.0	0.0	1.0
	2.5 (132 2)	0.0	227.0	7.0	309 0
	5.0 (264.3)	1.3	20.7	102.7	387.3
4	1.0 (52.9)	0.0	1.0	0.0	1.0
	2.5 (132.2)	0.0	1.0	0 0	1.0
	5.0 (264.3)	0.0	1.0	0.0	1.0
5	1.0 (52.9)	0.0	1.0	0.0	1.0
	2.5 (132.2)	0.1	42.3	10.3	175 0
	5.0 (264.3)	2.0	36.3	50.3	348.3
6	1.0 (52.9)	—	—	—	—
	2 5 (132.2)	0.0	1.0	0.0	1.0
	5.0 (264.3)	0.9	28.0	28.9	222.3
7	1 0 (52.9)	0.0	1.0	0.0	1.0
	2.5 (132.2)	0.0	6.0	0.2	9.3
	5.0 (264 3)	2 3	20.3	33 7	281.3
8	1.0 (52.9)	0.0	1.0	0.0	1.0
	2.5 (132.2)	0.0	1.0	0.0	1.0
	5.0 (264 3)	0.0	64.7	1.6	113.3
9	1.0 (52 9)	—	—	—	—
	2.5 (132 2)	0 0	1.0	0 0	1.0
	5.0 (264.3)	0.9	23.3	25.8	298.3
10	1.0 (52.9)	0.0	1.0	0.0	1.0
	2.5 (132 2)	0.0	1 0	0.0	1.0
	5.0 (264.3)	0.0	21.0	3.4	55.7
11	1.0 (52.9)	0.0	1.0	0 0	1.0
	2.5 (132 2)	0.0	21.3	1.9	135.3
	5.0 (264 3)	2 7	25.3	60.6	405.3
12	1.0 (52 9)	0.0	1.0	0.0	1.0
	2.5 (132 2)	0.0	1.0	0.0	1.0
	5.0 (264 3)	0.9	27.3	67.5	412 3
13	1 0 (52.9)	0.0	1.0	0.0	1.0
	2 5 (132.2)	0.1	35.7	6.3	96.3
	5 0 (264 3)	2.6	24.7	50.3	418 3

Table 19.—Heat Release as Measured in the OSU Release Rate Apparatus — Vertical Flaming — Task 2

System number	Incident heat flux, W/cm^2 (Btu/ft^2/min)	Maximum heat release rate, dQ/dt		Total heat release, Q
		W/cm^2 (Btu/ft^2/min	Time, sec.	W•sec/cm^2 (Btu/ft^2)
1	1.0 (52.9)	0.7 (37.0)	17.7	133.4 (117.5)
	2.5 (132.2)	4.5 (237.9)	32.7	177.2 (156.1)
	5.0 (264.3)	6.5 (343.6)	13.3	512.4 (451.5)
2	1.0 (52 9)	0.6 (31.7)	53.7	168.9 (148.8)
	2.5 (132.2)	1.3 (68.7)	34.7	290.4 (255.9)
	5.0 (264.3)	5.0 (264.3)	32.7	541.4 (477.0)
3	1.0 (52.9)	0.4 (21.1)	20.3	112.6 (99.2)
	2.5 (132.2)	3.6 (190.3)	29.7	538.6 (474.6)
	5.0 (264.3)	10.5 (555.1)	25.0	1334.5(1175.9)
4	1.0 (52.9)	0.5 (26.4)	2.0	91.1 (80.3)
	2.5 (132.2)	0.7 (37.0)	20.7	258.8 (228.0)
	5.0 (264.3)	1.7 (89.9)	23.3	252.7 (222.7)
5	1.0 (52.9)	0.5 (26.4)	32.3	127.6 (112.4)
	2 5 (132 2)	1.0 (52.9)	40.3	275.5 (242.8)
	5.0 (264.3)	6.4 (338.4)	30.0	515.1 (453.9)
6	1.0 (52.9)	— (—)	—	— (—)
	2 5 (132.2)	1.7 (89.9)	37.7	174.2 (153.5)
	5.0 (264.3)	4.7 (248.5)	36.0	574.7 (506.4)
7	1.0 (52.9)	0.9 (47.6)	25.0	166.9 (147.1)
	2.5 (132.2)	3.1 (163.9)	33.3	220.9 (194.6)
	5.0 (264.3)	6.9 (364.8)	17.7	401.5 (353.8)
8	1 0 (52.9)	0.6 (31.7)	11.0	144.5 (127.3)
	2.5 (132 2)	0.6 (31.7)	32.0	156.0 (137.5)
	5.0 (264.3)	2.3 (121.6)	34.0	195.1 (171.9)
9	1.0 (52.9)	— (—)	—	— (—)
	2.5 (132 2)	2.3 (121.6)	44.3	295.1 (260.0)
	5.0 (264.3)	4.8 (253.8)	33.7	590.5 (520.3)
10	1 0 (52.9)	0.3 (15.9)	2.0	53.0 (46 7)
	2 5 (132.2)	0.8 (42.3)	19.0	126.0 (111.0)
	5 0 (264.3)	2.5 (132.2)	27.3	96.3 (84.9)
11	1.0 (52.9)	0.4 (21.1)	31.0	82.7 (72.9)
	2 5 (132.2)	1.4 (74.0)	33.7	273.1 (240.6)
	5.0 (264 3)	5.8 (306.6)	21.7	641.5 (565.3)
12	1.0 (52.9)	0.5 (26.4)	114.0	91.9 (81.0)
	2.5 (132.2)	0.7 (37.0)	22.0	106.8 (94.1)
	5 0 (264.3)	4.2 (222.0)	23.0	481.4 (424.2)
13	1 0 (52.9)	0.9 (47.6)	31.0	147.2 (129.7)
	2.5 (132.2)	3.6 (190.3)	29.0	272.6 (240.2)
	5.0 (264.3)	6.8 (359.5)	17.3	403.4 (355.5)

Table 20.– Heat Release as Measured in the OSU Release Rate Apparatus – Horizontal Flaming – Task 2

System number	Incident heat flux, W/cm^2 (Btu/ft^2/min)	Maximum heat release rate, dQ/dt		Total heat release, Q
		W/cm^2 (Btu/ft^2/min	Time, sec.	W•sec/cm^2 (Btu/ft^2)
1	1.0 (52.9)	0.4 (21.1)	27.3	124.1 (109.3)
	2.5 (132 2)	1.9 (100.4)	67.5	284.7 (250.9)
	5.0 (264.3)	5.1 (269.6)	23.3	477.0 (420.3)
2	1.0 (52.9)	0.3 (15.9)	11.3	79.2 (69.8)
	2.5 (132.2)	0.7 (37.0)	86.3	160.9 (141.8)
	5 0 (264.3)	3.3 (174.5)	47.7	559.1 (492.6)
3	1.0 (52 9)	0.3 (15.9)	109.5	70.9 (62.5)
	2.5 (132 2)	1.0 (52.9)	251.7	336.8 (296.8)
	5.0 (264.3)	6.8 (359.5)	27.7	1289.1(1135.9)
4	1.0 (52.9)	0.3 (15.9)	4.0	37.4 (33.0)
	2.5 (132.2)	0.5 (26.4)	5.3	105.5 (93.0)
	5.0 (264.3)	0.9 (47.6)	30.3	91.1 (80.3)
5	1.0 (52.9)	0.4 (21.1)	46.5	129.0 (113.7)
	2.5 (132.2)	1 2 (63.4)	42.7	217.6 (191.7)
	5 0 (264.3)	4.3 (227.3)	41.7	782.8 (689 8)
6	1.0 (52 9)	– (–)	–	– (–)
	2.5 (132.2)	0.7 (37.0)	69 3	134.4 (118.4)
	5.0 (264 3)	3.6 (190 3)	40.7	659 8 (581.4)
7	1 0 (52.9)	0.4 (21.1)	28.3	85.9 (75.7)
	2 5 (132.2)	0.7 (37.0)	17.3	135.1 (119.0)
	5.0 (264 3)	6.0 (317.2)	29.7	442.3 (389.7)
8	1.0 (52.9)	0.2 (10.6)	39.0	53.5 (47.1)
	2.5 (132.2)	0.6 (31.7)	29.3	120.7 (106.4)
	5.0 (264 3)	1.9 (100.4)	38.0	248.3 (218.8)
9	1.0 (52.9)	– (–)	–	– (–)
	2.5 (132.2)	1.0 (52.9)	54.0	172 9 (152.3)
	5.0 (264.3)	4.0 (211 5)	38 0	712 3 (627.6)
10	1 0 (52.9)	0 3 (15 9)	4.0	52.8 (46.5)
	2.5 (132 2)	0.5 (26 4)	15 0	91.5 (80.6)
	5.0 (264 3)	1.4 (74.0)	25 3	55.2 (48 6)
11	1.0 (52.9)	0 3 (15.9)	41.0	30 4 (26 8)
	2.5 (132 2)	0.7 (37.0)	66.7	163.2 (143.8)
	5.0 (264 3)	4 0 (211.5)	32.3	477 6 (420 8)
12	1.0 (52 9)	0 3 (15.9)	58.0	45.4 (40.0)
	2.5 (132 2)	0.6 (31.7)	5.0	106.1 (93.5)
	5.0 (264 3)	2.2 (116.3)	61.7	419.5 (369.6)
13	1.0 (52.9)	0.4 (21.1)	27.7	102.4 (90.2)
	2.5 (132.2)	1.8 (95 2)	61.7	341.6 (301.0)
	5 0 (264.3)	5.4 (285.5)	32.7	545.5 (480.7)

Table 21.—Heat Release as Measured in the Boeing Burn Through Apparatus — Task 2

System number	Maximum heat release rate, dQ/dt W/cm^2 (Btu/ft^2/min)	Total heat release, Q W·sec/cm^2 (Btu/ft^2)
1	5.6 (296.1)	459.1 (404.5)
2	4.1 (216.8)	243.9 (214.9)
3	7.5 (396.5)	707.1 (623.1)
4	4.0 (211.5)	262.2 (231.0)
5	4.1 (216.8)	596.6 (501.9)
6	5.9 (311.9)	612.5 (539.7)
7	6.2 (327.8)	416.7 (367.2)
8	4.6 (243.2)	202.1 (178.1)
9	7.1 (375.4)	760.8 (670.4)
10	4.2 (222.0)	182.9 (161.2)
11	6.8 (359.5)	554.9 (488.9)
12	4.4 (232.6)	223.7 (197.1)
13	6.3 (333.1)	475.6 (419.1)

Table 22.—Backface Temperature — Boeing Burn Through Apparatus — Task 2

Time, sec.	Backface temperature, °C (°F) System												
	1	2	3	4	5	6	7	8	9	10	11	12	13
0	172 (342)	129 (264)	121 (250)	252 (486)	91 (196)	104 (219)	114 (237)	194 (381)	122 (252)	119 (246)	110 (230)	117 (243)	122 (252)
10	145 (293)	112 (234)	113 (235)	217 (423)	78 (172)	92 (198)	103 (217)	164 (327)	106 (223)	107 (225)	98 (208)	103 (217)	108 (226)
20	132 (270)	105 (221)	98 (208)	191 (376)	69 (156)	68 (154)	88 (190)	146 (295)	86 (187)	110 (230)	83 (181)	96 (205)	96 (205)
30	148 (298)	114 (237)	96 (205)	209 (408)	67 (153)	68 (154)	88 (190)	156 (313)	78 (172)	175 (347)	96 (205)	127 (261)	91 (196)
60	234 (453)	225 (437)	164 (327)	317 (603)	152 (306)	56 (133)	127 (261)	262 (504)	114 (237)	332 (630)	222 (432)	276 (529)	139 (282)
90	312 (594)	283 (541)	248 (478)	369 (696)	227 (441)	74 (165)	197 (387)	315 (599)	217 (423)	397 (747)	309 (588)	357 (675)	214 (417)
120	361 (682)	325 (617)	306 (583)	381 (718)	271 (520)	110 (230)	258 (496)	337 (639)	279 (534)	421 (790)	352 (666)	393 (739)	261 (502)
150	376 (709)	349 (660)	339 (642)	393 (739)	297 (567)	159 (318)	297 (567)	358 (676)	319 (606)	437 (819)	372 (702)	407 (765)	295 (563)
180	388 (730)	367 (693)	357 (675)	393 (739)	317 (603)	191 (376)	317 (603)	367 (693)	343 (649)	446 (835)	376 (709)	419 (786)	312 (594)
210	391 (736)	376 (709)	373 (703)	397 (747)	324 (615)	216 (421)	331 (628)	374 (705)	355 (671)	452 (846)	386 (727)	421 (790)	324 (615)
240	399 (750)	385 (725)	385 (725)	401 (754)	331 (628)	240 (464)	338 (640)	381 (718)	363 (685)	463 (865)	388 (730)	426 (799)	326 (619)
270	399 (750)	385 (725)	389 (732)	401 (754)	333 (631)	252 (486)	341 (646)	387 (729)	367 (693)	474 (885)	388 (730)	431 (808)	331 (628)
300	405 (761)	388 (730)	394 (741)	404 (759)	336 (637)	264 (507)	348 (658)	393 (739)	367 (693)	480 (896)	388 (730)	436 (817)	336 (637)

Table 22.– (Concluded)

Time, sec	Backface temperature, °C (°F)												
	System												
	1	2	3	4	5	6	7	8	9	10	11	12	13
330	408 (766)	391 (736)	397 (747)	404 (759)	338 (640)	264 (507)	350 (662)	398 (748)	371 (700)	487 (909)	388 (730)	441 (826)	338 (640)
360	408 (766)	393 (739)	397 (747)	408 (766)	343 (649)	271 (520)	352 (666)	399 (750)	371 (700)	494 (921)	400 (752)	448 (838)	338 (640)
390	411 (772)	393 (739)	402 (756)	411 (772)	343 (649)	277 (531)	359 (678)	406 (763)	374 (705)	498 (928)	400 (752)	454 (849)	338 (640)
420	414 (777)	397 (747)	406 (763)	414 (777)	343 (649)	277 (531)	362 (684)	407 (765)	374 (705)	504 (939)	400 (752)	464 (867)	341 (646)
450	420 (788)	399 (750)	408 (766)	414 (777)	346 (655)	277 (531)	362 (684)	410 (770)	374 (705)	508 (946)	402 (756)	467 (873)	343 (649)
480	423 (793)	399 (750)	408 (766)	414 (777)	346 (655)	277 (531)	362 (684)	412 (774)	379 (714)	511 (952)	407 (765)	474 (885)	343 (649)
510	432 (810)	406 (763)	408 (766)	418 (784)	348 (658)	283 (541)	367 (693)	416 (781)	383 (721)	518 (964)	409 (768)	481 (898)	346 (655)
540	435 (815)	406 (763)	410 (770)	418 (784)	350 (662)	283 (541)	372 (702)	417 (783)	383 (721)	518 (964)	414 (777)	481 (898)	348 (658)
570	444 (831)	414 (777)	412 (774)	418 (784)	350 (662)	289 (552)	374 (705)	418 (784)	387 (729)	522 (972)	417 (783)	485 (905)	350 (662)
600	450 (842)	417 (783)	414 (777)	421 (790)	352 (666)	289 (552)	374 (705)	421 (790)	387 (729)	523 (973)	419 (786)	485 (905)	350 (662)

Table 23.—Toxic Gas Emission as Measured in the NBS Smoke Chamber — Task 2

System number	Incident heat flux, W/cm^2 (Btu/ft^2/min)	Concentration at 4.0 minutes, ppm					Concentration at 10.0 minutes, ppm				
		HCN	NO_x	CO	HCl	SO_2	HCN	NO_x	CO	HCl	SO_2
1	1.0 (52.9)	Trace	Trace	87.0	–	–	–	–	–	–	–
	2.5 (132.2)	1.0	4.0	165.0	1.5	0.0	2.0	9.0	–	–	0.0
	5.0 (264.3)	3.0	3.0	430.0	–	–	–	–	–	–	–
2	1.0 (52.9)	1.0	10.0	85 0	–	–	–	–	–	–	–
	2.5 (132.2)	1.0	6.5	97.5	0.0	0.0	1.5	12 0	–	–	–
	5.0 (264.3)	3.0	16.5	359.0	–	–	–	–	–	–	–
3	1.0 (52.9)	1.5	–	46 0	–	–	2.0	–	–	–	–
	2.5 (132.2)	2.0	–	58.0	–	–	6.0	–	–	–	–
	5.0 (264.3)	15.5	–	285.0	–	–	35.0	–	–	–	–
4	1.0 (52 9)	1.0	5.0	68.0	–	–	–	–	–	–	–
	2.5 (132.2)	2.0	6.0	56.0	0.0	0.0	3.0	10.0	–	–	–
	5.0 (264.3)	2.0	5.0	98.0	–	–	–	–	–	–	–
5	1 0 (52.9)	1.0	7.0	81.0	–	–	–	–	–	–	–
	2 5 (132.2)	2.0	5.0	120.0	2.0	–	5.0	12.0	–	–	–
	5 0 (264.3)	5.0	10.0	403.0	–	–	–	–	–	–	–
6	1.0 (52.9)	–	–	–	–	–	–	–	–	–	–
	2.5 (132.2)	2.5	–	82.5	–	–	5.5	–	225.0	–	–
	5.0 (264.3)	11.5	–	277.5	–	–	40.0	–	862.5	–	–
7	1.0 (52.9)	1.5	–	43.0	–	–	2.0	–	–	–	–
	2.5 (132.2)	3.0	–	100.0	–	–	7.0	–	–	–	–
	5.0 (264 3)	16.0	–	460.0	–	–	33.0	–	–	–	–
8	1.0 (52.9)	1.0	6.0	67.0	–	–	–	–	–	–	–
	2 5 (132.2)	2.0	6.0	86.0	0.0	–	3.5	10.0	–	–	–
	5.0 (264.3)	10.0	10.0	183.0	–	–	–	–	–	–	–
9	1.0 (52.9)	–	–	–	–	–	–	–	–	–	–
	2.5 (132.2)	2.0	–	77.5	–	–	6.0	–	180.0	–	–
	5.0 (264.3)	14.0	–	260.0	–	–	40.0	–	680.0	–	–
10	1.0 (52.9)	0.0	–	42.5	–	–	Trace	–	92.5	–	–
	2.5 (132.2)	Trace	–	105.0	–	–	1.0	–	345.0	–	–
	5.0 (264.3)	2.5	–	425.0	–	–	10.0	–	1075.0	–	–
11	1.0 (52.9)	0.0	–	45.0	–	–	0 5	–	90.0	–	–
	2.5 (132.2)	1.0	–	95.0	–	–	2.0	–	267.5	–	–
	5.0 (264.3)	3.5	–	295.0	–	–	6.0	–	780.0	–	–
12	1.0 (52.9)	0 0	–	22.5	–	–	Trace	–	55.0	–	–
	2.5 (132.2)	Trace	–	67.5	–	–	1.0	–	197.5	–	–
	5.0 (264.3)	1.5	–	192.5	–	–	3.5	–	687.5	–	–
13	1 0 (52 9)	2.0	–	46.0	–	–	2.5	–	–	–	–
	2.5 (132.2)	7.0	–	93.0	–	–	9 5	–	–	–	–
	5.0 (264.3)	19.0	–	450.0	–	–	35 0	–	–	–	–

Table 24.—Apparent Lethal Concentrations of Pyrolysis Products — ALC_{50} — Task 2

Material	Resin content, %	System number	***ALC_{50}, mg/liter (oz/yd^3)	
			Measured	Normalized to 100% resin
FIBERITE MXB-7203*	42.0	1	—	—
FIBERITE MXB-7251**	47.0	1	71.4 (1.9)	33.6 (0.9)
NARMCO 8250*	35.0	2&5	—	—
NARMCO 9251**	47.4	2&5	119.2 (3.2)	56.5 (1.5)
HEXCEL 531*	—	3	—	—
HEXCEL 532**	—	3	—	—
DUPONT PYRALIN 3002*	—	4,6,8,&9	—	—
DUPONT PYRALIN 3002**	—	4,6,8,&9	—	—
RHODIA KERIMID 601*	—	7&13	—	—
RHODIA KERIMID 601**	—	7&13	—	—
CIBA-GEIGY FIBREDUX 917G*	46.0	10	133.0 (3.6)	61.2 (1.7)
CIBA-GEIGY FIBREDUX 917G**	41.7	10	119.3 (3.2)	49.7 (1.3)
FIBERITE MXB-6070*	28.3	11&12	228.6 (6.2)	64.7 (1.7)
FIBERITE MXB-7255**	48.7	11&12	87.3 (2.4)	42.5 (1.1)

* FACESHEET
** BOND PLY
*** BASED ON WEIGHT CHARGED

Table 25.—Thermogravimetric Analysis — Face Sheets — Task 2

Temperature, °C (°F)	Weight remaining, %						
	Ciba-Geigy Fibredux 917G	Dupont Pyralin 3002	Fiberite MXB-7203	Fiberite MXB-6070	Hexcel 531	Rhodia Kerimid 601	Narmco 8250
0 (32)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
50 (122)	100 0	100 0	100.0	100.0	100.0	100 0	100.0
100 (212)	100.0	100.0	100.0	100.0	99.9	99.6	100 0
150 (302)	99.8	100.0	100.0	99 9	99.1	98.8	100.0
200 (392)	99.6	99.9	100.0	99.8	98.3	98.8	100.0
250 (482)	99 0	99 2	100.0	99.7	97.3	98.8	99.3
300 (572)	97 2	98 8	99.9	99.6	96.7	98 8	98.9
350 (662)	96.6	98 5	99.2	99.5	96.1	98 5	98.5
400 (752)	95.3	98.1	95.3	98.3	94.6	96.6	97.1
450 (842)	93.3	97.8	91.9	96.2	91.6	93.3	95.0
500 (932)	90.4	97.6	90.2	92.6	88.3	90.4	91.9
550 (1022)	87.2	96.7	86.7	88.6	82.9	86.7	87.2
600 (1112)	84.5	92.3	83.6	85.3	77.0	81.6	82.3
650 (1202)	83.3	87 8	81.6	82.9	72.9	75.9	78.6
665 (1229)	83.2	—	—	—	—	—	—
675 (1247)	—	86.9	—	—	—	—	—
695 (1283)	—	—	80.3	—	—	—	—
700 (1292)	—	—	—	81.0	70.1	70.9	76.1
715 (1319)	—	—	—	80.9	—	—	—
750 (1382)	—	—	—	—	67.9	66.9	74.6
800 (1472)	—	—	—	—	65.9	63.9	74.4
810 (1490)	—	—	—	—	65.4	—	—
825 (1517)	—	—	—	—	—	63.2	—
850 (1562)	—	—	—	—	—	—	74.2

Table 26.—Thermogravimetric Analysis — Bond Plies — Task 2

Temperature, °C (°F)	Weight remaining, %						
	Fiberite MXB-7251	Dupont Pyralin 3002	Ciba-Geigy Fibredux 917G	Fiberite MXB-7255	Narmco 9251	Rhodia Kerimid 601	Hexcel 532
0 (32)	100.0	100.0	100.0	100.0	100 0	100.0	100.0
50 (122)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
100 (212)	100.0	100.0	100.0	99.9	99.6	99.0	99.5
150 (302)	99.8	100.0	100.0	99.7	97.4	98.5	98.8
200 (392)	99.6	97.4	99 3	99.6	94.1	98.5	97.9
250 (482)	99.4	96.2	97.4	99.4	91.7	98.5	95.3
300 (572)	98.8	95.0	92.1	99.4	89.7	98.5	92.8
350 (662)	93.4	94.8	90.4	98.6	85.4	98.1	90.9
400 (752)	82.3	94 8	88.6	97.0	83.2	96 3	84.9
450 (842)	78.3	94.1	86.5	91.7	79.4	92.6	75.0
500 (932)	75.2	93.5	82.5	87.8	72.6	89.3	68.7
550 (1022)	68.6	92.1	76.6	81.7	66.7	85.4	64.4
600 (1112)	63.3	85.7	68 5	75.4	59.8	79.6	57.1
650 (1202)	60.2	78.6	63.7	70.9	55.2	73.6	50.1
660 (1220)	59.8	–	–	–	–	–	-
695 (1283)	–	75.9	–	–	–	–	–
700 (1292)	–	–	59.7	67.5	51.7	68.5	45.2
750 (1382)	–	–	58.0	65.0	49.3	64.3	40.9
800 (1472)	–	–	57.5	63.4	47.1	61.3	37.9
805 (1481)	–	–	57.4	–	–	–	–
810 (1490)	–	–	–	63.3	–	–	–
815 (1499)	–	–	–	–	46.8	–	–
850 (1562)	–	–	–	–	–	59.8	35.0
900 (1652)	–	–	–	–	–	–	32.5

Table 27.—Thermogravimetric Analysis — Cores — Task 2

Temperature, °C (°F)	Weight remaining, %		
	Polyimide/ fiberglass	Polyimide/ polyamide	Phenolic/ polyamide
0 (32)	100.0	100.0	100.0
50 (122)	100.0	100.0	100.0
100 (212)	98.6	98.8	98.2
150 (302)	98.6	97.3	98.0
200 (392)	98.6	97.1	97.9
250 (482)	98.6	96.9	97.8
300 (572)	98.6	95.9	97.0
350 (662)	98.6	95.5	95.7
400 (752)	98.6	94.4	94.0
450 (842)	98.2	91.0	88.8
500 (932)	96.4	87.7	81.2
550(1022)	91.0	74.2	69.8
600(1112)	78.5	56.8	55.9
650(1202)	65.5	39.1	39.2
700(1292)	57.4	26.1	26.4
750(1382)	51.3	17.2	16.8
800(1472)	46.3	10.0	10.0
845(1553)	44.2	—	—
850(1562)	—	3.1	3.8
870(1598)	—	—	3.4

Table 28.—Thermogravimetric Analysis — Foams — Task 2

Temperature, °C (°F)	Weight remaining, %			
	Pyrolyzed ICU	PQ	Last-A-Foam FR-15017-2	ICU
0 (32)	100.0	100.0	100.0	100.0
50 (122)	100.0	100.0	100.0	100.0
100 (212)	99.5	98.9	97.7	100.0
150 (302)	98.3	95.6	96.4	99.1
200 (392)	98.3	92.8	96.3	96.5
250 (482)	98.3	87.9	95.8	94.1
300 (572)	98.3	84.8	93.6	75.0
350 (662)	98.1	81.7	85.4	66.1
400 (752)	95.3	76.3	81.4	62.3
450 (842)	86.5	70.3	77.4	57.7
500 (932)	70.2	62.9	73.4	48.6
550(1022)	48.0	54.4	62.3	35.5
600(1112)	18.5	46.5	39.5	22.6
650(1202)	9.8	36.3	20.6	12.5
665(1229)	8.8	—	—	—
700(1292)	—	21.8	6.6	10.8
715(1319)	—	18.3	—	—
720(1328)	—	—	3.7	—
750(1382)	—	—	—	7.8
800(1472)	—	—	—	5.5
840(1544)	—	—	—	5.0

Table 29.—Thermogravimetric Analysis — Adhesives — Task 2

Temperature, °C (°F)	Weight remaining,%	
	American Cyanamid BR-34	American Cyanamid FM-34
0 (32)	100.0	100.0
50 (122)	99.9	99.9
100 (212)	99.8	99.9
150 (302)	99.6	99.8
200 (392)	99.5	99.5
250 (482)	99.1	99.0
300 (572)	98.5	98.2
350 (662)	97.2	97.4
400 (752)	96.7	96.6
450 (842)	96.1	96.0
500 (932)	94.5	95.1
550(1022)	90.7	91.7
600(1112)	86.0	85.1
650(1202)	81.4	79.7
700(1292)	76.6	76.2
750(1382)	73.1	73.6
765(1409)	73.0	—
780(1436)	—	72.7

Table 30.—Differential Thermal Analysis — Task 2

System number	Material	Total heat released, J/gm (Btu/lb)
	FACE SHEET	
1	FIBERITE MXB-7203	101.2 (43.5)
2&5	NARMCO 8250	141.8 (61.0)
3	HEXCEL 531	170.4 (73.3)
4,6,8,&9	DUPONT PYRALIN 3002	93.0 (40.0)
7&13	RHODIA KERIMID 601	157.8 (67.9)
10	CIBA-GEIGY FIBREDUX 917G	116.0 (49.9)
11&12	FIBERITE MXB-6070	117.1 (50.4)
	BOND PLY	
1	FIBERITE MXB-7251	120.8 (52.0)
2&5	NARMCO 9251	177.4 (76.3)
3	HEXCEL 532	222.5 (95.7)
4,6,8,&9	DUPONT PYRALIN 3002	137.6 (59.2)
7&13	RHODIA KERIMID 601	181.1 (77.9)
10	CIBA-GEIGY FIBREDUX 917G	169.3 (72.8)
11&12	FIBERITE MXB-7255	152.8 (65.7)
	ADHESIVE	
4,6,8,&9	BR-34 (AMERICAN CYANAMID)	143.0 (61.5)
7&13	FM-34 (AMERICAN CYANAMID)	133.7 (57.5)
	FOAM	
5&11	ICU (UPJOHN CPR-9545, 2.3 PCF)	584.8 (251.6)
6&9	PI/PU (GENERAL PLASTICS LAST-A-FOAM FR-15017-2)	534.8 (230.1)
7	PQ	392.5 (168.9)
13	PYROLYZED ICU	934.1 (401.9)
	CORE	
1,2,3,5, 10,11,&12	PHENOLIC/POLYAMIDE (0.125 in. CELL, 3 PCF)	457.0 (196.6)
4&6	POLYIMIDE/FIBERGLASS (0.1875 in. CELL, 4.5 PCF)	201.1 (86.5)
8&9	POLYIMIDE/POLYAMIDE (0.125 in. CELL, 3 PCF)	465.3 (200.2)

Table 31.—Peel Strength — Task 2

System number	Peel strength, cm•kg/7.62 cm width (in•lb/3 in. width)	
	Face skin	Back skin
1	17.2 (14.9)	15.6 (13.5)
2	15.7 (13.6)	15.6 (13.5)
3	10.1 (8.8)	25.9 (22.5)
4	5.3 (4.6)	5.5 (4.8)
5	10.7 (9.3)	11.5 (10.0)
6	10.8 (9.4)	13.1 (11.4)
7	7.9 (6.9)	6.3 (5.5)
8	15.0 (13.0)	14.2 (12.3)
9	14.9 (12.9)	11.9 (10.3)
10	11.5 (10.0)	9.8 (8.5)
11	19.9 (17.3)	21.8 (18.9)
12	19.0 (16.5)	18.7 (16.2)
13	9.2 (8.0)	9.6 (8.3)

Table 32.—Flatwise Tensile Strength — Task 2

System number	Flatwise tensile strength, kg/cm^2 (lb/in^2)	Principal failure mode
1	24.8 (352.7)	core - core
2	22.6 (321.4)	core - core
3	27.8 (395.4)	core - core
4	48.5 (689.8)	adhesive - adhesive
5	17.7 (251.8)	bond ply - face sheet
6	16.5 (234.7)	adhesive - adhesive
7	4.5 (64.0)	core - adhesive
8	21.7 (308.6)	core - core
9	25.9 (368.4)	core - core
10	16.2 (230.4)	core - bond ply
11	28.0 (398.3)	core - core
12	26.1 (371.2)	core - core
13	16.9 (240.4)	core - core

Table 33.—Impact Strength — Gardener — Task 2

System number	Impact strength, cm•kg (in•lb)
1	10.4 (9.0)
2	8.8 (7.6)
3	13.1 (11.4)
4	5.4 (4.7)
5	8.1 (7.0)
6	7.1 (6.2)
7	12.7 (11.0)
8	8.1 (7.0)
9	5.8 (5.0)
10	10.7 (9.3)
11	6.9 (6.0)
12	8.1 (7.0)
13	12.9 (11.2)

Table 34.—Density — Task 2

System number	Thickness, cm (in)	Density, kg/m^2 (lb/ft^2)
1	0.703 (0.277)	1.42 (0.291)
2	0.703 (0.277)	1.62 (0.332)
3	0.696 (0.274)	1.80 (0.369)
4	0.696 (0.274)	1.55 (0.317)
5	0.691 (0.272)	1.74 (0.356)
6	1.021 (0.402)	3.02 (0.619)
7	0.630 (0.248)	1.94 (0.397)
8	0.688 (0.271)	1.64 (0.336)
9	0.711 (0.280)	2.28 (0.467)
10	0.688 (0.271)	1.29 (0.264)
11	0.688 (0.271)	1.48 (0.303)
12	0.688 (0.271)	1.34 (0.274)
13	0.660 (0.260)	1.91 (0.391)

Table 35.—Limiting Oxygen Index — Decorative Films — Task 3

Film number	Material	LOI, % O_2
1,2,4,&5	0.025mm (0.001in) CLEAR TEDLAR + DUPONT 6880	46.0
1	0.051mm (0.002in) WHITE TEDLAR	30.0
2	0.025mm (0.001in) FM TEDLAR	67.8
3	0.038mm (0.0015in) CLEAR FLUOREX H	25.9
3	0.051mm (0.002in) WHITE FLUOREX H	59.7
4	0.127mm (0.005in) WHITE POLYCARBONATE	30.0
5	0.127mm (0.005in) CLEAR POLYETHERSULFONE	31.6
1	FILM NO. 1	24.9
2	FILM NO. 2	28.9
3	FILM NO. 3	36.8
4	FILM NO. 4	40.7
5	FILM NO. 5	25.9

Table 36.—Smoke Emission as Measured in the NBS Smoke Chamber — Task 3

Film number	Incident heat flux, W/cm^2 ($Btu/ft^2/min$)	Specific optical density			Time to reach D_M (corr.), min
		D_S @ 1.5 min	D_S @ 4.0 min	D_M (corr.)	
1	1.0 (52.9)	1.9	1.8	1.9	1.0
	2.5 (132.2)	13.0	13.1	13.7	1.0
	5.0 (264.3)	16.3	15.8	16.3	1.0
2	1.0 (52.9)	0.0	0.0	0.0	0.0
	2.5 (132.2)	10.9	11.1	11.1	4.0
	5.0 (264.3)	15.4	15.3	15.4	1.5
3	1.0 (52.9)	0.1	0.3	0.5	5.0
	2.5 (132.2)	5.3	5.8	6.6	0.5
	5.0 (264.3)	8.8	9.2	9.2	4.0
4	1.0 (52.9)	0.6	3.8	47.4	20.0
	2.5 (132.2)	17.2	39.5	127.0	20.0
	5.0 (264.3)	36.2	74.9	110.0	10.0
5	1.0 (52.9)	1.2	1.3	1.3	4.0
	2.5 (132.2)	5.8	5.5	7.1	0.5
	5.0 (264.3)	11.0	12.1	12.9	10.0

Table 37.—FAA Flammability — Vertical, 60 sec. — Task 3

Film number	Extinguishing time, sec.	Drip extinguishing time, sec.	Burn length, cm (in)
1	0.0	1.0	14.5 (5.7)
2	0.0	No drip	12.4 (4.9)
3	0.0	No drip	11.7 (4.6)
4	0.0	No drip	15.0 (5.9)
5	0.0	No drip	13.5 (5.3)

Table 38.—Toxic Gas Emission as Measured in the NBS Smoke Chamber —Task 3

Film number	Incident heat flux, W/cm^2 ($Btu/ft^2/min$)	Concentration at 4.0 minutes, ppm			
		HCN	HF	CO	SO_2
1	1.0 (52.9)	—	35.0	82.0	—
	2.5 (132.2)	—	145.0	—	—
	5.0 (264.3)	—	145.0	137.0	—
2	1.0 (52.9)	—	15.0	75.0	—
	2.5 (132.2)	—	55.0	—	—
	5.0 (264.3)	—	140.0	112.0	—
3	1.0 (52.9)	—	42.0	80.0	—
	2.5 (132.2)	—	240.0	—	—
	5.0 (264.3)	—	310.0	323.0	—
4	1.0 (52.9)	—	20.0	78.0	—
	2.5 (132.2)	—	44.0	—	—
	5.0 (264.3)	—	90.0	180.0	—
5	1.0 (52.9)	—	16.0	76.0	Trace
	2.5 (132.2)	Trace	50.0	—	18.0
	5.0 (264.3)	—	75.0	170.0	37.5

Table 39.–Pyrolysis Tube Decomposition – Task 3

Film number	Material	mg HF/gm of sample (gr HF/oz of sample)		mg SO_2/gm of sample (gr SO_2/oz of sample)
		Quartz	Monel	Monel
1,2,4,&5	0.025mm (0.001in) CLEAR TEDLAR*	–	173.0 (75.7)	–
1	0.051mm (0.002in) WHITE TEDLAR	–	156.0 (68.3)	–
2	0.025mm (0.001in) FM TEDLAR	–	168.0 (73.5)	–
3	0.051mm (0.002in) WHITE FLUOREX H	–	197.0 (86.2)	–
5	0.127mm (0.005in) CLEAR POLYETHERSULFONE	–	–	97.0 (42.4)
1	FILM NO. 1	41.8 (18.3)	74.1 (32.4)	–
2	FILM NO. 2	45.5 (19.9)	103.5 (45.3)	–
3	FILM NO. 3	109.9 (48.1)	184.9 (80.9)	–
4	FILM NO. 4	18.8 (8.2)	27.5 (12.0)	–
5	FILM NO. 5	8.6 (3.8)	15.7 (6.9)	–

* Coated one side with Dupont 6880 adhesive.

Table 40.—Apparent Lethal Concentrations of Pyrolysis Products — ALC_{50} — Task 3

Film number	ALC_{50}, mg/liter (oz/yd^3)	
	Based on weight charged	Based on weight pyrolyzed
1	65.0 (1.8)	38.0 (1.0)
2	110.0 (3.0)	73.0 (2.0)
3	45.0 (1.2)	34.0 (0.9)
4	48.0 (1.3)	33.0 (0.9)
5	78.0 (2.1)	42.0 (1.1)

Table 41.—Decorative Film Relative Toxicity — Task 3

	NBS chamber	Pyrolysis tube decomposition	NASA animal exposure chamber
MOST HF OR MOST TOXIC	PVF_2/PVF_2	PVF_2/PVF_2	PVF_2/PVF_2
↓	PVF/PVF	PVF/FM-PVF	PVF/PC
	PVF/FM-PVF	PVF/PVF	PVF/PVF
LEAST HF OR LEAST TOXIC	PVF/PC	PVF/PC	PVF/PES
	PVF/PES	PVF/PES	PVF/FM-PVF

Table 42.—Decorative Film Elongation — Task 3

Film number	Material	Elongation, %
1,2,4,&5	0.025mm (0.001in) CLEAR TEDLAR*	48.6
1	0.051mm (0.002in) WHITE TEDLAR	63.0
2	0.025mm (0.001in) FM TEDLAR	37.8
3	0.038mm (0.0015in) CLEAR FLUOREX H	7.0
3	0.051mm (0.002in) WHITE FLUOREX H	14.2
4	0.127mm (0.005in) WHITE POLYCARBONATE	14.0
5	0.127mm (0.005in) CLEAR POLYETHERSULFONE	21.4
1	FILM NO. 1	63.0
2	FILM NO. 2	40.8
3	FILM NO. 3	7.8
4	FILM NO. 4	5.0
5	FILM NO. 5	29.8

* Coated one side with Dupont 6880 adhesive.

Table 43.—Ultraviolet Stability — Task 3

Film number	Exposure time			
	20 Hours	80 Hours	140 Hours	295 Hours
1	Excellent	Excellent	Excellent	Excellent
2	Excellent	Excellent	Excellent	Excellent
3	Excellent	Excellent	Excellent	Excellent
4	Excellent	Excellent	Excellent	Excellent
5	Excellent	Excellent	Excellent	Excellent

Table 44.—Decorative Film Peel Strength — Task 4

System number	Ultimate load, kg (lb)	Comments
A-1	2.2 (4.9)	Film broke. No peel.
A-2	1.6 (3.5)	Film broke. No peel.
A-3	2.7 (6.0)	Film broke. No peel.
A-4	2.5 (5.5)	Film broke. No peel.
A-5	5.3 (11.7)	Film broke. 12.7mm (0.5in) peel.
B-1	1.0 (2.2)	Film broke. No peel.
B-2	1.7 (3.7)	Film broke. No peel.
B-3	1.0 (2.2)	Film broke. No peel.
B-4	1.5 (3 3)	Film broke. No peel
B-5	2.5 (5 5)	Film broke. No peel.

Table 45.—Decorative Film Abrasion Test — Taber Abraser — Task 4

System number	Cycles to first sign of damage	Cycles to failure	Weight loss at failure, %
A-1	500	2500	1.83
A-2	500	2500	1.89
A-3	500	2500	1.82
A-4	500	2500	1.72
A-5	500	4000	2.99
B-1	500	500	0.28
B-2	500	500	0.32
B-3	500	500	0.29
B-4	500	500	0.25
B-5	500	500	0.41

Table 46.—Decorative Film Wear Test — Wyzenbeek Method — Task 4

System number	Cycles to first sign of damage	Cycles to failure
A-1	1500	3500
A-2	1500	3500
A-3	1500	3500
A-4	1500	3500
A-5	3500	4500
B-1	500	1000
B-2	500	1500
B-3	500	1500
B-4	500	1500
B-5	500	1000

Table 47.—Decorative Laminate Evaluation — Task 4

System number	Background color		Opaqueness	"Cut-through"*	Texture
A-1	White	(1)	(1)	None	Satisfactory
A-2	Off color	(4)	(3)	None	Satisfactory
A-3	Off color	(3)	(2)	None	Satisfactory
A-4	Off color	(3)	(2)	None	Satisfactory
A-5	Off color	(2)	(1)	Minor	Fair
B-1	Off color	(2)	(5)	Minor	Takes texture well
B-2	Off color	(6)	(5)	Bad	Takes texture well
B-3	Off color	(7)	(4)	Bad	Takes texture well
B-4	Off color	(5)	(4)	Minor	Takes texture well
B-5	Off color	(5)	(4)	Bad	Takes texture well

* "Cut-through" — Base film, base ink coat, or other ink layers are penetrated or broken in texturing process exposing layers beneath.

Note: The numbers in parentheses represent a value ordering on a scale of 1 to 10 (1 is best).

Table 48.—Materials Matrix — Task 5

Panel number	Decorative film	Facesheet		Bond ply		Honeycomb core		Foam
1	PVF*/ACRYLIC INK/PVF**	EPOXY	FIBERITE MXB-7203	EPOXY	FIBERITE MXB-7251	PHENOLIC/ POLYAMIDE	3PCF NOMEX	NONE
2	PVF*/ACRYLIC INK/PVF**	PHENOLIC	CIBA-GEIGY FIBREDUX 917G	PHENOLIC	CIBA-GEIGY FIBREDUX 917G	PHENOLIC/ POLYAMIDE	3PCF NOMEX	NONE
3	PVF*/ACRYLIC INK/PVF**	PHENOLIC	CIBA-GEIGY FIBREDUX 917G	PHENOLIC	CIBA-GEIGY FIBREDUX 917G	PHENOLIC/ POLYAMIDE	3PCF NOMEX	PHENOLIC 2.5 PCF

* 0.025mm (0.001in) PVF top film
** 0.051mm (0.002in) PVF substrate film

Table 49.—Smoke Emission as Measured in the NBS Smoke Chamber — Flaming — Task 5

Panel number	Incident heat flux, W/cm^2 (Btu/ft^2/min)	Specific optical density				Time to reach D_M, min.	Weight loss	
		D_S @ 1.5 min	D_S @ 4.0 min	D_S @ 10.0 min	D_M		kg (lb)x10^3	%
1	1.0 (52.9)	6.4	11.2	15.4	16.1	14.0	0.5 (1.1)	3.3
	2.5 (132.2)	49.0	56.4	53.5	57.9	5.0	1.4 (3.1)	9.2
	5.0 (264.3)	96.5	125.2	117.5	128.4	5.6	4.1 (9.0)	26.1
2	1.0 (52.9)	1.6	2.9	4.4	5.0	15.9	0.9 (2.0)	5.7
	2.5 (132.2)	9.9	14.5	17.8	18.0	9.9	0.9 (2.0)	5.7
	5.0 (264.3)	68.3	113.3	100.5	115.0	4.1	3.8 (8.4)	23.3
3	1.0 (52.9)	0.8	2.0	4.3	5.0	16.1	0.7 (1.5)	3.6
	2.5 (132.2)	13.1	18.7	19.8	20.6	7.7	2.2 (4.9)	11.3
	5.0 (264.3)	46.5	62.7	59.8	67.0	5.4	4.6(10.1)	23.4

Table 50.—Smoke Emission as Measured in the NBS Smoke Chamber — Smoldering — Task 5

Panel number	Incident heat flux, W/cm^2 (Btu/ft^2/min)	Specific optical density				Time to reach D_M, min.	Weight loss	
		D_S @ 1.5 min	D_S @ 4.0 min	D_S @ 10.0 min	D_M		kg (lb)x10^3	%
1	1.0 (52.9)	0.0	0.1	0.2	0.3	17.3	0.1 (0.2)	0.5
	2.5 (132.2)	9.7	19.3	24.5	25.1	13.4	1.0 (2.2)	6.6
	5.0 (264.3)	66.6	101.9	117.7	119.6	8.3	2.6 (5.7)	16.8
2	1.0 (52.9)	0.2	0.4	0.4	0.6	11.9	0.5 (1.1)	2.7
	2.5 (132.2)	2.0	2.8	4.3	4.6	14.5	1.0 (2.2)	6.1
	5.0 (264.3)	24.0	43.6	52.6	96.9	10.8	3.6 (7.9)	21.6
3	1.0 (52.9)	0.2	0.6	0.6	0.7	12.4	0.3 (0.7)	1.4
	2.5 (132.2)	2.4	2.9	3.3	3.6	17.1	1.9 (4.2)	9.5
	5.0 (264.3)	30.7	41.4	46.3	47.3	8.5	4.7(10.4)	24.0

Table 51.—Smoke Emission as Measured in the OSU Release Rate Apparatus — Vertical Flaming -- Task 5

Panel number	Incident heat flux, W/cm^2 (Btu/ft^2/min)	Maximum smoke release rate, d(Ds)/dt				Specific optical density			
		sec^{-1}	σ, sec^{-1}	Time, sec.	σ, sec.	Max.	σ	Time, sec.	σ, sec.
1	1.0 (52.9)	0.2	0.2	25.2	5.4	4.8	0.5	61.2	9.7
	2.5 (132.2)	5.4	1.2	22.8	1.1	71.4	12.6	81.4	52.4
	5.0 (264.3)	13.0	0.5	13.5	2.5	176.6	19.9	569.8	59.0
2	1.0 (52.9)	0.0	0.0	18.3	5.0	1.0	0.3	35.7	3.1
	2.5 (132.2)	1.8	0.8	19.0	5.3	19.6	3.6	44.6	7.1
	5.0 (264.3)	4.2	1.3	11.2	3.7	53.3	13.2	256.0	49.4
3	1.0 (52.9)	0.0	0.0	14.8	4.3	1.2	1.1	59.8	55.1
	2.5 (132.2)	1.4	0.6	24.2	13.5	17.6	3.8	53.6	14.4
	5.0 (264.3)	5.9	1.3	11.4	4.4	37.3	3.9	72.6	30.9

Table 52.—Smoke Emission as Measured in the OSU Release Rate Apparatus — Horizontal Flaming — Task 5

Panel number	Incident heat flux, W/cm^2 (Btu/ft^2/min)	Maximum smoke release rate, d(Ds)/dt				Specific optical density			
		sec^{-1}	σ, sec^{-1}	Time, sec.	σ, sec.	Max.	σ	Time, sec.	σ, sec.
1	1.0 (52.9)	0.1	0.2	27.8	4.9	5.2	2.3	100.6	42.3
	2.5 (132.2)	3.9	0.9	38.6	11.4	97.2	11.7	395.2	246.7
	5.0 (264.3)	11.1	1.3	23.7	4.7	247.0	30.5	470.3	78.3
2	1.0 (52.9)	0.0	0.0	59.8	105.8	1.1	0.6	84.6	107.3
	2.5 (132.2)	1.1	0.2	41.0	4.7	16.5	2.3	103.6	71.5
	5.0 (264.3)	4.1	0.2	15.7	1.5	114.2	10.1	447.3	42.0
3	1.0 (52.9)	0.0	0.0	47.8	64.7	1.5	1.4	77.4	66.9
	2.5 (132.2)	0.7	0.2	36.8	1.6	11.9	3.1	59.2	6.1
	5.0 (264.3)	4.7	0.9	15.0	0.0	62.6	10.2	505.3	115.4

Table 53.—Heat Release as Measured in the OSU Release Rate Apparatus — Vertical Flaming — Task 5

Panel number	Incident heat flux, W/cm^2 (Btu/ft^2/min)	Maximum heat release rate, dQ/dt				Total heat release, Q	
		W/cm^2 (Btu/ft^2/min)	σ, W/cm^2 (Btu/ft^2/min)	Time, sec.	σ, sec	W•sec/cm^2 (Btu/ft^2)	σ, W•sec/cm^2 (Btu/ft^2)
1	1.0 (52.9)	0.8 (42.3)	0.1 (5.3)	31.6	5.0	202.7 (178.6)	47.4 (41.8)
	2.5 (132.2)	6.1 (322.5)	0.4 (21.1)	23.6	3.8	605.6 (533 6)	172.6 (152.1)
	5.0 (264.3)	7.6 (401 8)	0.9 (47.6)	12 5	1.7	1009.9(889.9)	270.3 (238.2)
2	1.0 (52.9)	0.4 (21.1)	0.1 (5.3)	40.3	21.1	123.1 (108.5)	13.2 (11.6)
	2.5 (132.2)	4.8 (253.8)	0.6 (31.7)	20.2	2.3	755.5 (665.7)	158.5 (139.7)
	5.0 (264.3)	6.8 (359.5)	0.9 (47.6)	11.0	1.6	963.5 (849.0)	494.5 (435 7)
3	1.0 (52.9)	0.3 (15.9)	0.1 (5.3)	189.6	204.5	132.5 (116.8)	43.4 (38.2)
	2.5 (132.2)	4.3 (227.3)	1.2 (63.4)	26.0	12.2	800.7 (705.5)	253.6 (223.5)
	5.0 (264.3)	6.4 (338.4)	0.5 (26.4)	12.0	2.5	1062.5(936.2)	319.2 (281.3)

Table 54.—Heat Release as Measured in the OSU Release Rate Apparatus — Horizontal Flaming — Task 5

Panel number	Incident heat flux, W/cm^2 (Btu/ft^2/min)	Maximum heat release rate, dQ/dt				Total heat release, Q	
		W/cm^2 (Btu/ft^2/min)	σ, W/cm^2 (Btu/ft^2/min)	Time, sec.	σ, sec.	W•sec/cm^2 (Btu/ft^2)	σ, W•sec/cm^2 (Btu/ft^2)
1	1.0 (52.9)	0.8 (42.3)	0.3 (15.9)	40.2	6.4	245.6 (216.4)	141.6 (124.8)
	2.5 (132.2)	4.0 (211.5)	0.2 (10.6)	44.4	4.4	566.6 (499.3)	166.5 (146.7)
	5.0 (264.3)	5.6 (296.1)	0.4 (21.1)	18.7	1.5	1581.1 (1393.2)	31.8 (28.0)
2	1.0 (52.9)	0.7 (37.0)	0.1 (5.3)	67.8	104.1	255.7 (225.3)	64.7 (57.0)
	2.5 (132.2)	2.5 (132.2)	0.2 (10.6)	37.8	5.0	522.8 (460.7)	79.5 (70.1)
	5.0 (264.3)	4.3 (227.3)	0.1 (5.3)	30.0	21.9	1656.8 (1459 9)	29.6 (26.1)
3	1.0 (52.9)	0.8 (42.3)	0.2 (10.6)	83.6	74.5	283.6 (249.9)	32.2 (28.4)
	2.5 (132.2)	2.3 (121.6)	0.7 (37.0)	36.8	1.6	528.8 (465.9)	233.6 (205.8)
	5.0 (264.3)	4.7 (248.5)	0.3 (15.9)	15.0	0.0	1372.5 (1209.4)	42.4 (37.4)

Table 55.—Heat Release as Measured in the Boeing Burn Through Apparatus — Task 5

Panel number	Maximum heat release rate, dQ/dt W/cm^2 (Btu/ft^2/min)	Total heat release, Q W • sec/cm^2 (Btu/ft^2)
1	6.4 (338.4)	455.2 (401.1)
2	4.2 (222.0)	254.3 (224.1)
3	4.8 (253.8)	334.2 (294.5)

Table 56.—Backface Temperature — Boeing Burn Through Apparatus — Task 5

Time, sec.	Backface temperature, ^{o}C (^{o}F)		
	Panel 1	Panel 2	Panel 3
0	83(181)	86(187)	88(190)
10	77(171)	86(187)	81(178)
20	65(149)	74(165)	69(156)
30	62(144)	62(144)	64(147)
60	68(154)	74(165)	64(147)
90	98(208)	106(223)	67(153)
120	144(291)	151(304)	71(160)
150	190(374)	209(408)	83(181)
180	228(442)	242(468)	105(221)
210	258(496)	275(527)	132(270)
240	280(536)	307(585)	159(318)
270	301(574)	319(606)	184(363)
300	316(601)	323(613)	207(405)
330	328(622)	331(628)	226(439)
360	331(628)	335(635)	239(462)
390	334(633)	343(649)	251(484)
420	337(639)	343(649)	253(487)
450	340(644)	343(649)	261(502)
480	343(649)	347(657)	266(511)
510	343(649)	351(664)	273(523)
540	343(649)	355(671)	273(523)
570	343(649)	355(671)	280(536)
600	346(655)	359(678)	283(541)

Table 57.—Toxic Gas Emission as Measured in the NBS Smoke Chamber -- Flaming — Task 5

Panel number	Incident heat flux, W/cm^2 (Btu/ft^2/min)	Concentration at 4.0 min., ppm			Concentration at 10.0 min., ppm		
		CO	HF	HCN	CO	HF	HCN
1	1.0 (52.9)	85	63	0	131	51	0
	2.5 (132.2)	227	80	1	373	68	1
	5.0 (264.3)	530	89	5	990	118	14
2	1.0 (52.9)	61	44	—	130	37	—
	2.5 (132.2)	194	69	Trace	505	55	2
	5.0 (264.3)	753	46	5	1875	156	11
3	1.0 (52.9)	55	64	—	143	40	—
	2.5 (132.2)	293	74	Trace	778	74	2
	5.0 (264.3)	885	98	7	2288	49	14

Table 58.—Toxic Gas Emission as Measured in the NBS Smoke Chamber — Smoldering -- Task 5

Panel number	Incident heat flux, W/cm^2 (Btu/ft^2/min)	Concentration at 4.0 min., ppm			Concentration at 10.0 min., ppm		
		CO	HF	HCN	CO	HF	HCN
1	1.0 (52.9)	4	33	—	10	20	—
	2.5 (132.2)	68	84	0	123	62	Trace
	5.0 (264.3)	397	167	5	865	215	19
2	1.0 (52.9)	0	21	—	5	22	—
	2.5 (132.2)	78	88	0	205	87	Trace
	5.0 (264.3)	569	163	5	1938	317	20
3	1.0 (52.9)	0	16	—	8	37	—
	2.5 (132.2)	105	70	0	345	85	Trace
	5.0 (264.3)	867	198	5	2788	146	15

Table 59.—Peel Strength — Task 5

Panel number	Peel strength, cm•kg/7.62cm width (in•lb/3 in. width)
1	9.9 (8.6)
2	9.0 (7.8)
3	12.0 (10.4)

Table 60.—Flatwise Tensile Strength — Task 5

Panel number	Flatwise tensile strength, kg/cm^2 (lb/in^2)	Principal failure mode
1	19.0 (270.2)	core - core
2	24.5 (348.5)	core - core
3	20.4 (290.2)	core - bond ply

Table 61.—Beam Flexure — Task 5

Panel number	Stress, kg/cm Width (lb/in Width)	Modulus, kg/cm^2 (lb/in^2) $\times 10^{-4}$
1	70.2 (393.1)	21.2 (301.5)
2	56.0 (313.6)	20.4 (290.2)
3	58.0 (324.8)	19.3 (274.5)

Table 62.—Taber Abrasion — Task 5

Panel number	Weight loss, gram (ounce)		Cycles to failure
	1000 cycles	Failure	
1	0.0375 (0.0013)	0.0559 (0.0020)	1500
2	0.0445 (0.0016)	0.0656 (0.0023)	1450
3	0.0432 (0.0015)	0.0432 (0.0015)	1000

Table 63.—Flammability, Smoke, and Toxicity Improvements

	Baseline Epoxy	Developed Phenolic
Propensity to burn (LOI)		
Face sheet	29.0	100+
Adhesive	27.7	53.5
Smoke emission (D_S@ 4 min) NBS		
2.5 W/cm^2 (132.2 Btu/ft^2/min)	62.8	2.5
5.0 W/cm^2 (264.3 Btu/ft^2/min)	96.5	8.4
Heat release, W•sec/cm^2 (Btu/ft^2) OSU		
2.5 W/cm^2 (132.2 Btu/ft^2/min)	177.2 (156.1)	126.0 (111.0)
5.0 W/cm^2 (264.3 Btu/ft^2/min)	512.4 (451.5)	96.3 (84.9)
	Baseline PVF/PVF	Developed PVF/PC
Gas release — HF — mg/gm (gr/oz)		
Monel tube Pyrolysis	74.1 (32.4)	27.5 (12.0)

Table 64.—Limiting Oxygen Index (LOI)

System number	Face sheet	Bond ply	Adhesive	Core	Foam	Adhesive	Bond ply	Bond ply
1	29.0	27.7	—	30.9	—	—	27.7	27.7
2	50.7	32.3	—	30.9	—	—	32.3	32.3
3	33.9	24.6	—	30.9	—	—	24.6	24.6
4	100.0*	—	49.8	58.9	—	49.8	71.4	71.4
5	50.7	32.3	—	30.9	23.0	—	32.3	32.3
6	100.0*	—	49.8	58.9	27.7	49.8	71.4	71.4
7	56.0	52.6	58.9	30.9**	***	58.9	52.6	52.6
8	100.0*	—	49.8	35.2	—	49.8	71.4	71.4
9	100.0*	—	49.8	35.2	27.7	49.8	71.4	71.4
10	100.0*	53.5	—	30.9	—	—	53.5	53.5
11	65.8	23.0	—	30.9	23.0	—	23.0	23.0
12	65.8	23.0	—	30.9	—	—	23.0	23.0
13	56.0	52.6	58.9	30.9**	63.5	58.9	52.6	52.6

*Does not burn in 100% oxygen — assumption.
**1.8 PCF honeycomb core and not run — assumption.
***PQ foam and not run — assumption.

Table 65.—Smoke Emission — NBS Chamber

System number	D_S AT 1.0 W/cm^2 (52.9 Btu/ft^2/min)			D_S AT 2.5 W/cm^2 (132.2 Btu/ft^2/min)			D_S AT 5.0 W/cm^2 (264.3 Btu/ft^2/min)		
	1.5 min.	4.0 min.	Max.	1.5 min.	4.0 min.	Max.	1.5 min.	4.0 min.	Max.
1	7.2	9.3	12.1	58.4	62.8	79.9	94.7	96.5	164.0
2	0.0	0.0	0.0	1.3	2.1	5.4	6.4	10.1	12.5
3	0.0	0.3	5.2	7.1	19.5	64.7	15.9	34.4	85.6
4	0.0	0.0	0.0	0.1	0.3	1.5	0.1	0.5	1.1
5	0.0	0.0	0.0	0.5	1.2	20.6	15.3	23.9	38.4
6	0.0*	0.0*	0.0*	12.0	32.0	36.4	9.3	28.7	35.7
7	0.8	1.2	3.3	8.8	11.2	12.0	14.4	15.8	14.8
8	0.0	0.0	0.0	0.3	0.6	2.9	1.7	4.6	6.8
9	0.0*	0.0*	0.0*	8.8	20.5	24.6	8.4	19.9	35.9
10	0.6	0.8	0.7	1.7	2.5	1.3	4.5	8.4	10.9
11	0.1	0.2	0.6	3.4	4.7	12.4	22.0	34.4	44.1
12	0.0	0.0	0.0	0.8	1.0	6.2	6.6	16.3	52.5
13	1.2	1 7	2.5	8.6	11.2	10.5	21.8	24.4	22.4

*Not run — assumption

Table 66.—Toxic Gas Emission — NBS Chamber

System number	ppm CO at 4.0 minutes			ppm HCN at 4.0 minutes			ppm HCN at 10.0 mins.
	1.0 W/cm^2 (52.9 Btu/ft^2/min)	2.5 W/cm^2 (132.2 Btu/ft^2/min)	5.0 W/cm^2 (264.3 Btu/ft^2/min)	1.0 W/cm^2 (52.9 Btu/ft^2/min)	2.5 W/cm^2 (132.2 Btu/ft^2/min)	5.0 W/cm^2 (264.3 Btu/ft^2/min)	2.5 W/cm^2 (132.2 Btu/ft^2/min)
1	87.0	165.0	430.0	0.0*	1.0	3.0	2.0
2	85.0	97.5	359.0	1.0	1.0	3.0	1.5
3	46.0	58.0	285.0	1.5	2.0	15.5	6.0
4	68.0	56.0	98.0	1.0	2.0	2.0	3.0
5	81.0	120.0	403.0	1.0	2.0	5.0	5.0
6	68.0**	82.5	277.5	1.0**	2.5	11.5	5.5
7	43.0	100.0	460.0	1.5	3.0	16.0	7.0
8	67.0	86.0	183.0	1.0	2.0	10.0	3.5
9	67.0**	77.5	260.0	1.0**	2.0	14.0	6.0
10	42.5	105.0	425.0	0.0	0.0*	2.5	1.0
11	45.0	95.0	295.0	0.0	1.0	3.5	2.0
12	22.5	67.5	192.5	0.0	0.0*	1.5	1.0
13	46.0	93.0	450.0	2.0	7.0	19.0	9.5

*Actually a trace — assumption.
**Not run — assumption.

Table 67.—Total Heat Release — Boeing Burn Through

System number	Heat release, W•sec/cm^2
1	459.1
2	243.9
3	707.1
4	262.2
5	569.6
6	612.5
7	416.7
8	202.1
9	760.8
10	182.9
11	554.9
12	223.7
13	475.6

Table 68.—Maximum Heat Release Rate — Boeing Burn Through

System number	Heat release rate, W/cm^2
1	5.6
2	4.1
3	7.5
4	4.0
5	4.1
6	5.9
7	6.2
8	4.6
9	7.1
10	4.2
11	6.8
12	4.4
13	6.3

Table 69.—Backface Temperature Rise — Boeing Burn Through

System number	Temperature at the end of 4.0 mins, °C
1	399
2	385
3	385
4	401
5	331
6	240
7	338
8	381
9	363
10	463
11	388
12	426
13	326

Table 70.—Total Heat Release — OSU — Vertical

System number	Heat release, W-sec/cm^2		
	1.0 W/cm^2 (52.9 Btu/ft^2/min)	2.5 W/cm^2 (132.2 Btu/ft^2/min)	5.0 W/cm^2 (264.3 Btu/ft^2/min)
1	133.4	177.2	512.4
2	168.9	290.4	541.4
3	112.6	538.6	1334.5
4	91.1	258.8	252.7
5	127.6	275.5	515.1
6	91.1*	174.2	574.7
7	166.9	220.9	401.5
8	144.5	156.0	195.1
9	144.5*	295.1	590.5
10	53.0	126.0	96.3
11	82.7	273.1	641.5
12	91.9	106.8	481.4
13	147.2	272.6	403.4

* Not run — assumption

Table 71.—Total Heat Release — OSU — Horizontal

System number	Heat release, W•sec/cm^2		
	1.0 W/cm^2 (52.9 Btu/ft^2/min)	2.5 W/cm^2 (132.2 Btu/ft^2/min)	5.0 W/cm^2 (264.3 Btu/ft^2/min)
1	124.1	284.7	477.0
2	79.2	160.9	559.1
3	70.9	336.8	1289.1
4	37.4	105.5	91.1
5	129.0	217.6	782.8
6	37.4*	134.4	659.8
7	85.9	135.1	442.3
8	53.5	120.7	248.3
9	53.5*	172.9	712.3
10	52.8	91.5	55.2
11	30.4	163.2	477.6
12	45.4	106.1	419.5
13	102.4	341.6	545.5

* Not run — assumption.

Table 72.—Maximum Heat Release Rate — OSU — Vertical

System number	Heat release rate, W/cm^2		
	1.0 W/cm^2 (52.9 Btu/ft^2/min)	2.5 W/cm^2 (132.2 Btu/ft^2/min)	5.0 W/cm^2 (264.3 Btu/ft^2/min)
1	0.7	4.5	6.5
2	0.6	1.3	5.0
3	0.4	3.6	10.5
4	0.5	0.7	1.7
5	0.5	1.0	6.4
6	0.5*	1.7	4.7
7	0.9	3.1	6.9
8	0.6	0.6	2.3
9	0.6*	2.3	4.8
10	0.3	0.8	2.5
11	0.4	1.4	5.8
12	0.5	0.7	4.2
13	0.9	3.6	6.8

* Not run — assumption.

Table 73.—Maximum Heat Release Rate — OSU — Horizontal

System number	Heat release rate, W/cm^2		
	1.0 W/cm^2 (52.9 Btu/ft^2/min)	2.5 W/cm^2 (132.2 Btu/ft^2/min)	5.0 W/cm^2 (264.3 Btu/ft^2/min)
1	0.4	1.9	5.1
2	0.3	0.7	3.3
3	0.3	1.0	6.8
4	0.3	0.5	0.9
5	0.4	1.2	4.3
6	0.3*	0.7	3.6
7	0.4	0.7	6.0
8	0.2	0.6	1 9
9	0.2*	1.0	4.0
10	0.3	0.5	1.4
11	0.3	0.7	4.0
12	0.3	0.6	2.2
13	0.4	1.8	5.4

* Not run — assumption.

Table 74.—Smoke Emission — OSU — Vertical

System number	1.0 W/cm^2 (52.9 Btu/ft^2/min)		2.5 W/cm^2 (132.2 Btu/ft^2/min)		5.0 W/cm^2 (264.3 Btu/ft^2/min)	
	D_M	$d(D_M)/dt$, sec^{-1}	D_M	$d(D_M)/dt$, sec^{-1}	D_M	$d(D_M)/dt$, sec^{-1}
1	8.7	0.4	103.1	6.4	179.1	16.0
2	0.0	0.0	1.6	0.0	24.2	0.9
3	0.0	0.0	17.5	0.3	83.1	1.7
4	0.0	0.0	0.0	0.0	1.3	0.0
5	0.0	0.0	5.2	0.0	70.4	5.2
6	0.0*	0.0*	2.4	0.0	18.4	0.9
7	1.2	0.0	3.9	0.1	29.2	2.7
8	0.0	0.0	0.0	0.0	9.2	0.3
9	0 0*	0.0*	2.0	0.0	41.4	2.4
10	0.0	0.0	0.4	0.0	11.1	0.4
11	0.7	0.0	9.9	0.4	112.2	8.4
12	0.1	0.0	5.3	0.0	56.5	2.4
13	1.7	0.0	6.2	0.3	65.3	5.7

*Not run — assumption.

Table 75.—Smoke Emission — OSU — Horizontal

System number	1.0 W/cm^2 (52.9 Btu/ft^2/min)		2.5 W/cm^2 (132.2 Btu/ft^2/min)		5.0 W/cm^2 (264.3 Btu/ft^2/min)	
	D_M	$d(D_M)/dt$, sec^{-1}	D_M	$d(D_M)/dt$, sec^{-1}	D_M	$d(D_M)/dt$, sec^{-1}
1	2.6	0.1	65.8	1.9	191.5	12.6
2	0.0	0.0	0.0	0.0	44.7	1.0
3	0.0	0.0	7.0	0.0	102.7	1.3
4	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	10.3	0.1	50.3	2.0
6	0.0*	0.0*	0.0	0.0	28.9	0.9
7	0.0	0.0	0.2	0.0	33.7	2.3
8	0.0	0.0	0.0	0.0	1.6	0.0
9	0.0*	0.0*	0.0	0.0	25.8	0.9
10	0.0	0.0	0.0	0.0	3.4	0.0
11	0.0	0.0	1.9	0.0	60.6	2.7
12	0.0	0.0	0.0	0.0	67.5	0.9
13	0.0	0.0	6.3	0.1	50.3	2.6

* Not run — assumption.

Table 76.—Total Heat Release — DTA

System number	Heat release, J/gm							
	Face sheet	Bond ply	Adhesive	Core	Foam	Adhesive	Bond ply	Bond ply
1	101.2	120.8	—	457.0	—	—	120.8	120.8
2	141.8	177.4	—	457.0	—	—	177.4	177.4
3	170.4	222.5	—	457.0	—	—	222.5	222.5
4	93.0	—	143.0	201.1	—	143.0	137.6	137.6
5	141.8	177.4	—	457.0	584.8	—	177.4	177.4
6	93.0	—	143.0	201.1	534.8	143.0	137.6	137.6
7	157.8	181.1	133.7	457.0*	392.5	133.7	181.1	181.1
8	93.0	—	143.0	465.3	—	143.0	137.6	137.6
9	93.0	—	143.0	465.3	534.8	143.0	137.6	137.6
10	116.0	169.3	—	457.0	—	—	169.3	169.3
11	117.1	152.8	—	457.0	584.8	—	152.8	152.8
12	117.1	152.8	—	457.0	—	—	152.8	152.8
13	157.8	181.1	133.7	457.0*	934.1	133.7	181.1	181.1

*1.8 PCF honeycomb core and not run — assumption.

Table 77.—Peel Strength

System number	cm•kg/7.62cm width	
	Face skin	Back skin
1	17.2	15.6
2	15.7	15.6
3	10.1	25.9
4	5.3	5.5
5	10.7	11.5
6	10.8	13.1
7	7.9	6.3
8	15.0	14.2
9	14.9	11.9
10	11.5	9.8
11	19.9	21.8
12	19.0	18.7
13	9.2	9.6

Table 78.—Flatwise Tensile Strength

System number	Tensile strength, kg/cm^2
1	24.8
2	22.6
3	27.8
4	48.5
5	17.7
6	16.5
7	4.5
8	21.7
9	25.9
10	16.2
11	28.0
12	26.1
13	16.9

Table 79.—Impact Strength

System number	Failure energy, cm·kg
1	10.4
2	8.8
3	13.1
4	5.4
5	8.1
6	7.1
7	12.7
8	8.1
9	5.8
10	10.7
11	6.9
12	8.1
13	12.9

Table 80.—Density

System number	Thickness, cm	Density, kg/cm^2
1	0.703	1.42
2	0.703	1.62
3	0.696	1.80
4	0.696	1.55
5	0.691	1.74
6	1.021	3.02
7	0.630	1.94
8	0.688	1.64
9	0.711	2.28
10	0.688	1.29
11	0.688	1.48
12	0.688	1.34
13	0.660	1.91

Table 81.—Normalized Composite Values — Method 1

Parameter	System 1	System 2	System 3	System 4	System 5	System 6	System 7	System 8	System 9	System 10	System 11	System 12	System 13
A_1	0 286	0.357	0 277	0.669	0.336	0 613	0.518	0.629	0 579	0.583	0.315	0.331	0.533
A_2	0.420	0 974	0 793	0.997	0.932	0 870	0 910	0 989	0.904	0 969	0.916	0.949	0.898
A_3	0.762	0.799	0 710	0.879	0.735	0 731	0.631	0.786	0.720	0.811	0.829	0.901	0.564
A_4	0.426	0.695	0.116	0.672	0.288	0.234	0.479	0.747	0 049	0.771	0.306	0.720	0.406
A_5	0 440	0.590	0.250	0.600	0.590	0.410	0.380	0.540	0 290	0 580	0 320	0 560	0.370
A_6	0.202	0.230	0.230	0.198	0.338	0.520	0 324	0 238	0 274	0 074	0.224	0 148	0.348
A_7	0.565	0.437	0 217	0.648	0.520	0.624	0.510	0 629	0.464	0 820	0 568	0.681	0.514
A_8	0.450	0.610	0 315	0.830	0.430	0.679	0.646	0 755	0.608	0 823	0.707	0.743	0.423
A_9	0.322	0.602	0.393	0 749	0.624	0.616	0 340	0.709	0 540	0.791	0.644	0.693	0.309
A_{10}	0.380	0.673	0.507	0.787	0.523	0 663	0 550	0.770	0 633	0 770	0 650	0 727	0.387
A_{11}	0.568	0.971	0.900	0.999	0.894	0 975	0.948	0.990	0.944	0.987	0 824	0.928	0 889
A_{12}	0 662	0.954	0.898	1.000	0.932	0.968	0.953	0.999	0 971	0 997	0.925	0.936	0.930
A_{13}	0.816	0.774	0.741	0.857	0.714	0.801	0.773	0.813	0.764	0.784	0 730	0.794	0.705.
A_{14}	0.547	0.522	0.600	0.180	0.370	0.398	0.237	0.487	0.447	0.355	0.695	0.628	0.313
A_{15}	0.496	0.452	0.556	0.970	0 354	0.330	0.090	0 434	0.518	0.324	0 560	0 522	0.338
A_{16}	0 520	0.440	0.655	0.270	0.405	0 355	0.635	0.405	0.290	0.535	0 345	0.405	0 645
A_{17}	0 498	0.473	0.449	0.480	0.455	0 378	0.415	0.467	0.393	0.511	0.487	0.505	0.426

Table 82.—Weighted Distribution of Test Data

Laboratory test	Weight, %	Property	Weight, %
Flammability	10	Limiting oxygen index (LOI)	10
Smoke emission	20	Smoke emission (NBS chamber)	10
		Smoke emission (OSU — vertical)	5
		Smoke emission (OSU — horizontal)	5
Toxic gas emission	10	Toxic gas emission (NBS chamber)	10
Heat release	20	Total heat release (Boeing burn through)	6
		Total heat release (OSU — vertical)	6
		Total heat release (OSU — Horizontal)	6
		Total heat release (DTA)	2
Heat release rate	20	Maximum heat release rate (Boeing burn through)	8
		Maximum heat release rate (OSU — vertical)	6
		Maximum heat release rate (OSU — horizontal)	6
Thermal conductivity	4	Backface temperature rise (Boeing burn through)	4
Mechanical strength	6	Peel strength	2
		Flatwise tensile strength	2
		Impact strength	2
Weight	10	Density	10

Table 83.—Total Assessment — Laboratory Tests — Method 1

System number	A_{LT}
1	0.478
2	0.638
3	0.486
4	0.725
5	0.578
6	0.617
7	0.572
8	0.699
9	0.568
10	0.714
11	0.596
12	0.673
13	0.539

Table 84.—Fabrication and Material Costs

System number	Material cost, $	Fabrication cost	
		Labor, hrs.	Misc., $
1	100.00	1.00	1.00
2	115.62	1.00	1.00
3	162.58	1.09	126.00
4	1307.20	4.43	670.38
5	197.73	1.00	1.60
6	1380.88	4.43	670.38
7	501.19	4.80	767.88
8	686.33	4.43	670.38
9	760.00	4.43	670.38
10	114.80	1.00	1.60
11	195.86	1.00	1.60
12	113.76	1.00	1.60
13	465.25	4.80	767.88

Table 85.—Normalized Composite Values — Method 1

System number	A_{18}
1	0.925
2	0.921
3	0.873
4	0.284
5	0.900
6	0.266
7	0.443
8	0.439
9	0.421
10	0.921
11	0.901
12	0.921
13	0.452

C – 3

Table 86.—Total Overall Assessment —.Method 1

System number	A_T
1	0.545
2	0.680
3	0.544
4	0.659
5	0.626
6	0.564
7	0.553
8	0.660
9	0.546
10	0.745
11	0.642
12	0.710
13	0.526

Table 87.—Normalized Composite Values — Method 2

Parameter	System 1	System 2	System 3	System 4	System 5	System 6	System 7	System 8	System 9	System 10	System 11	System 12	System 13
B_1	0.286	0.350	0.275	0.649	0.327	0.574	0.508	0.595	0.534	0.543	0.288	0.301	0.522
B_2	0.389	0.974	0.759	0.997	0.928	0.859	0 909	0.988	0.900	0 969	0.913	0.945	0.898
B_3	0.663	0 750	0.643	0.878	0.668	0.700	0.481	0.770	0 674	0 709	0.802	0.891	0.380
B_4	0.426	0.695	0.116	0.672	0.288	0.234	0.479	0.747	0 049	0.771	0.306	0.720	0.406
B_5	0.440	0 590	0.250	0 600	0.590	0.410	0.380	0.540	0.290	0.580	0.320	0.560	0.370
B_6	0.202	0.230	0.230	0 198	0.338	0.520	0.324	0.238	0.274	0.074	0.224	0.148	0.348
B_7	0.537	0.372	0 170	0 636	0.505	0.620	0.425	0.563	0.441	0.816	0.568	0.671	0.472
B_8	0.421	0.610	0.243	0.825	0.426	0.671	0.643	0.753	0.602	0 818	0.699	0.742	0.357
B_9	0.257	0.582	0.369	0.725	0.612	0.610	0.274	0.668	0.528	0 788	0.642	0.676	0.248
B_{10}	0.245	0.673	0.482	0.782	0.515	0.663	0.538	0 768	0 621	0 767	0.649	0.726	0 302
B_{11}	0 431	0.970	0.885	0.999	0.881	0.975	0.946	0.990	0.940	0 987	0.786	0.922	0.877
B_{12}	0.459	0 951	0.872	1.000	0.927	0.967	0.950	0.999	0.970	0.997	0.918	0.927	0.925
B_{13}	0.802	0 763	0.733	0.857	0.690	0.785	0.763	0.801	0.741	0.773	0.703	0.782	0.578
B_{14}	0.546	0.522	0.539	0.180	0.370	0.396	0 235	0.486	0.444	0.354	0.694	0.628	0.313
B_{15}	0.496	0 452	0.556	0.970	0 354	0.330	0.090	0.434	0.518	0.324	0.560	0.522	0.338
B_{16}	0.520	0 440	0.655	0.270	0.405	0.355	0.635	0.405	0.290	0.535	0.345	0.405	0.645
B_{17}	0.476	0.457	0.437	0.462	0.442	0.354	0.403	0.451	0.391	0.483	0.466	0.478	0.415

Table 88.—Total Assessment — Laboratory Tests — Method 2

System number	B_{LT}
1	0.408
2	0.584
3	0.395
4	0.670
5	0.528
6	0.565
7	0.498
8	0.651
9	0.473
10	0.637
11	0.535
12	0.612
13	0.461

Table 89.—Normalized Composite Values — Method 2

System number	B_{18}
1	0.922
2	0.918
3	0.872
4	0.259
5	0.897
6	0.245
7	0.269
8	0.357
9	0.347
10	0.918
11	0.898
12	0.918
13	0.272

Table 90.—Total Overall Assessment — Method 2

System number	B_T
1	0.461
2	0.625
3	0.445
4	0.581
5	0.572
6	0.498
7	0.454
8	0.595
9	0.452
10	0.673
11	0.578
12	0.650
13	0.426

Table 91.—OSU Release Rate Apparatus Data — Vertical Flaming — Foams — 5.0 W/cm^2 (264.3 Btu/ft^2/min)

Foam material	Maximum heat release rate, dQ/dt, W/cm^2 (Btu/ft^2/min)	Total heat release, Q, J/cm^2 (Btu/ft^2)	Maximum smoke release rate, d(D_S)/dt, min^{-1}	Specific optical density, D_M
Pyrolyzed ICU	3.7 (195.2)	310.8 (273.9)	10.2	3.4
PI/PU	4.4 (232.6)	524.0 (461.7)	14.6	4.7
Phenolic	2.8 (148.0)	437.6 (385.6)	4.3	2.7
PO	0.9 (46.3)	278.4 (245.3)	23.0	21.2

Table 92.—Boeing Burn Through Apparatus Data — Foams

Foam material	Maximum heat release rate, dQ/dt, W/cm^2 (Btu/ft^2/min)	Total heat release, Q, J/cm^2 (Btu/ft^2)
Pyrolyzed ICU	6.9 (364.8)	158.1 (139.3)
PI/PU	7.5 (396.5)	262.7 (231.5)
Phenolic	3.7 (195.6)	112.0 (98.7)
PQ	2.6 (137.5)	112.1 (98.8)

Table 93.—Boeing Burn Through Apparatus Data — Foams

Time, sec.	Backface temperature, °C (°F)			
	Pyrolyzed ICU	PI/PU	Phenolic	PQ
0	131 (268)	116 (240)	100 (212)	94 (201)
10	122 (252)	110 (230)	98 (208)	86 (186)
20	128 (263)	104 (219)	91 (195)	78 (172)
30	231 (447)	113 (235)	110 (230)	89 (193)
40	364 (687)	143 (290)	159 (318)	118 (244)
50	470 (878)	228 (442)	233 (452)	147 (296)
60	504 (940)	348 (659)	298 (568)	192 (378)
70	556 (1032)	447 (836)	357 (675)	258 (497)
80	567 (1052)	484 (904)	399 (750)	343 (649)
90	—	540 (1004)	426 (799)	426 (798)
100	—	543 (1010)	458 (857)	493 (919)
110	—	—	481 (898)	526 (979)
120	—	—	505 (941)	567(1052)
130	—	—	516 (960)	—
140	—	—	520 (968)	—
150	—	—	532 (990)	—
160	—	—	541(1005)	—

Table 94.—Normalized Composite Values — Method 1

Parameter	Pyrolyzed ICU	PI/PU	Phenolic	PQ
A1	0.482	0.127	0.271	0.536
A2	0.260	0.120	0.440	0.820
A3	0.728	0.614	0.860	0.116
A4	0.473	0.124	0.627	0.626
A5	0 310	0.250	0.630	0.740
A6	0.333	0.448	0.784	0.565

Table 95.—Total Assessment — Laboratory Tests — Method 1

Foam material	ALT
Pyrolyzed ICU	0.392
PI/PU	0.348
Phenolic	0.675
PQ	0.566

Table 96.—Material Cost — Foams

Foam material	Material cost, $
Pyrolyzed ICU	1.41
PI/PU	1.63
Phenolic	1.00
PQ	1.78

Table 97.—Normalized Composite Values — Method 1

Foam material	A7
Pyrolyzed ICU	0.295
PI/PU	0.185
Phenolic	0.500
PQ	0.110

Table 98.—Total Overall Assessment — Method 1

Foam material	AT
Pyrolyzed ICU	0.385
PI/PU	0.336
Phenolic	0.662
PQ	0.532

Table 99.—Normalized Composite Values — Method 2

Parameter	Pyrolyzed ICU	PI/PU	Phenolic	PQ
B1	0.482	0.127	0.271	0.536
B2	0.260	0.120	0.440	0.820
B3	0.715	0.581	0.859	0.110
B4	0.473	0.124	0.627	0.626
B5	0.310	0.250	0.630	0.740
B6	0.333	0.448	0.784	0.565

Table 100.—Total Assessment — Laboratory Tests — Method 2

Foam material	BLT
Pyrolyzed ICU	0.374
PI/PU	0.295
Phenolic	0.642
PQ	0.514

Table 101.—Normalized Composite Values—Method 2

Foam material	B7
Pyrolyzed ICU	0.295
PI/PU	0.185
Phenolic	0.500
PQ	0.110

Table 102.—Total Overall Assessment — Method 2

Foam material	BT
Pyrolyzed ICU	0.367
PI/PU	0.285
Phenolic	0.630
PQ	0.458

Figure 1.—Model 747 Interior

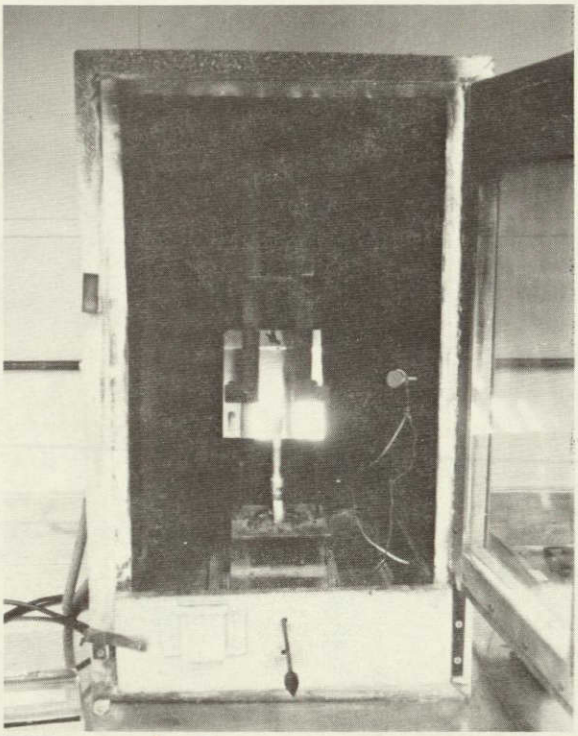


Figure2.—Vertical Burn Test Chamber, FAR 25-32 Type

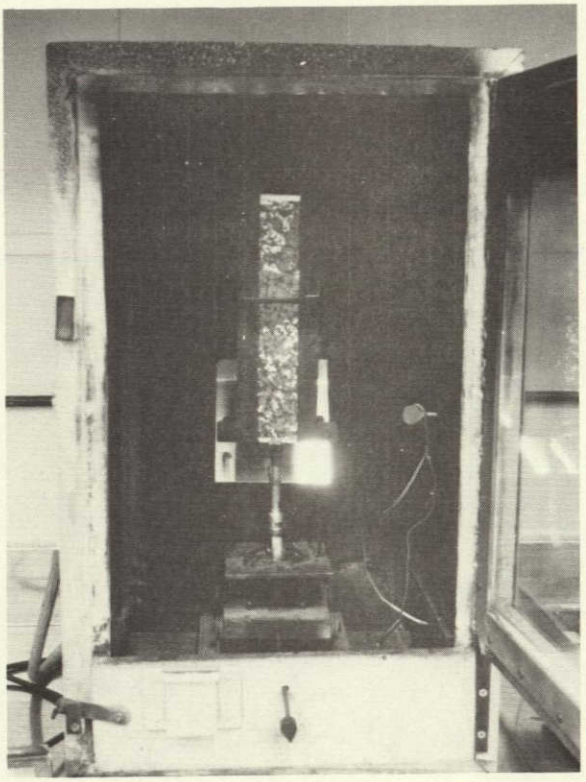


Figure 3.—Vertical Burn Test Chamber Showing Specimen and Burner Flame Positioning

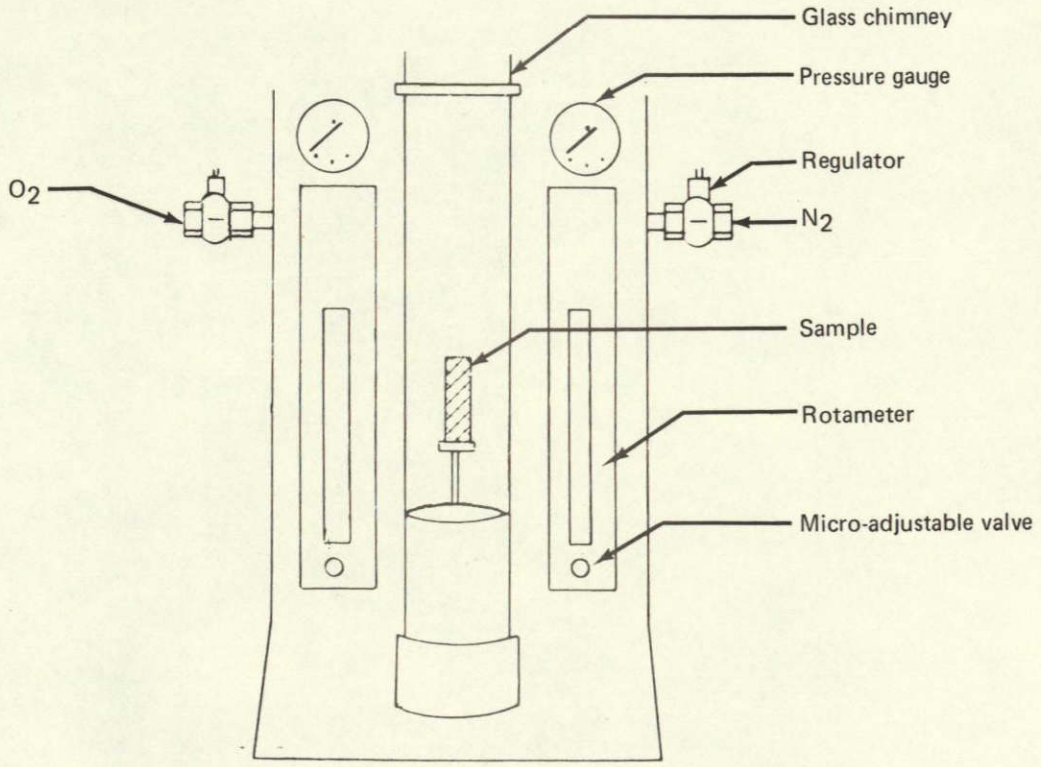


Figure 4.—Limiting Oxygen Index Test Apparatus

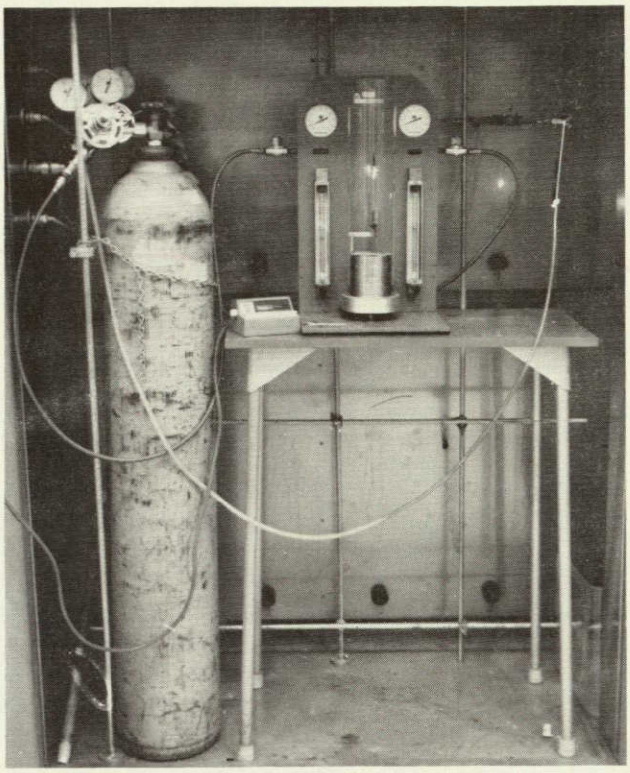


Figure 5.—Limiting Oxygen Index Test Apparatus

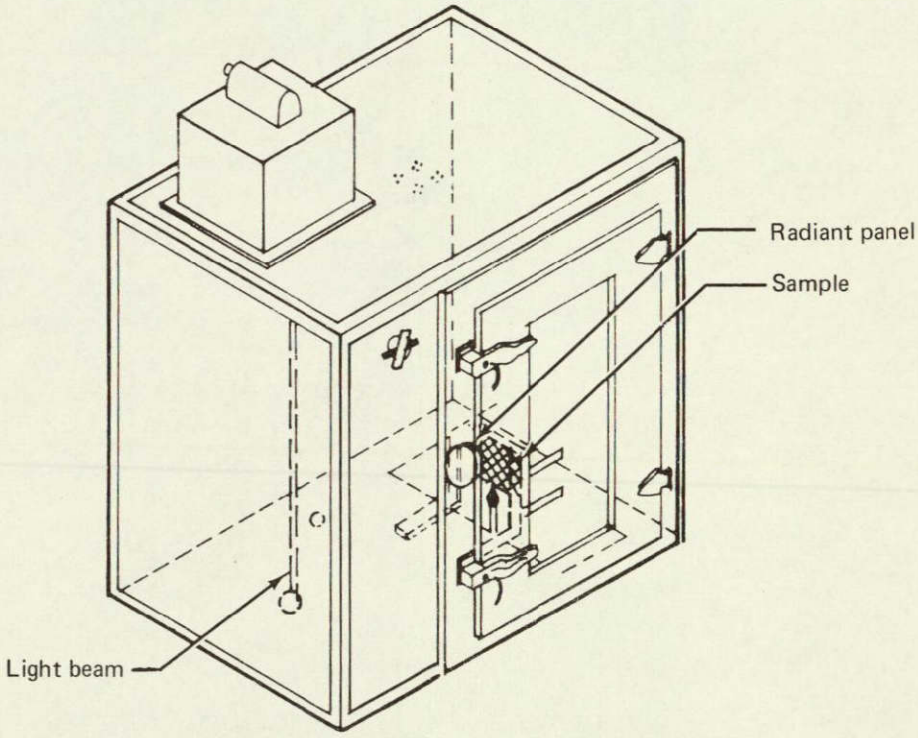


Figure 6.—National Bureau of Standards Smoke Chamber

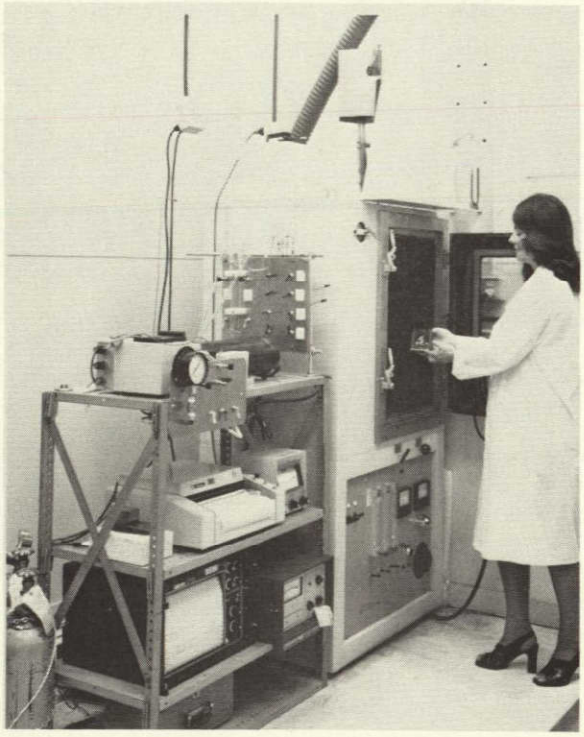


Figure 7.—Aminco–NBS Smoke Chamber

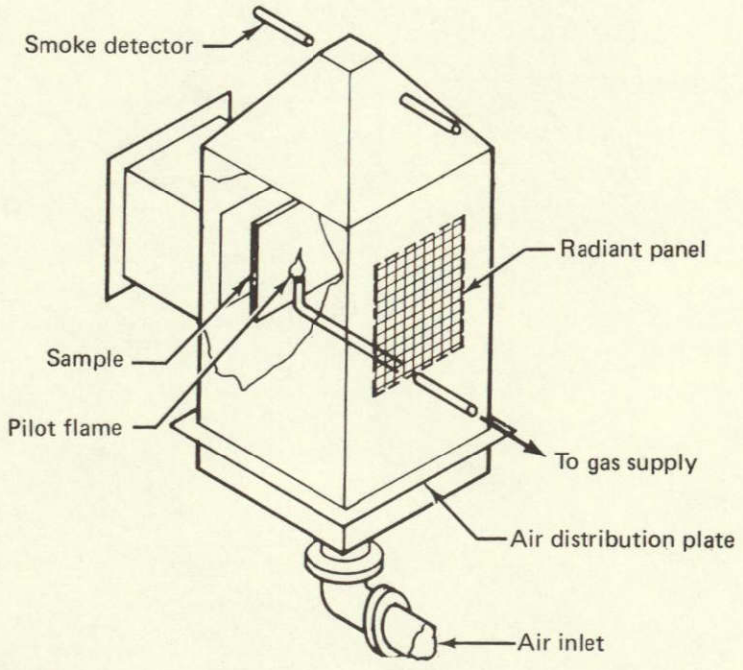


Figure 8.—Ohio State University Release Rate Apparatus

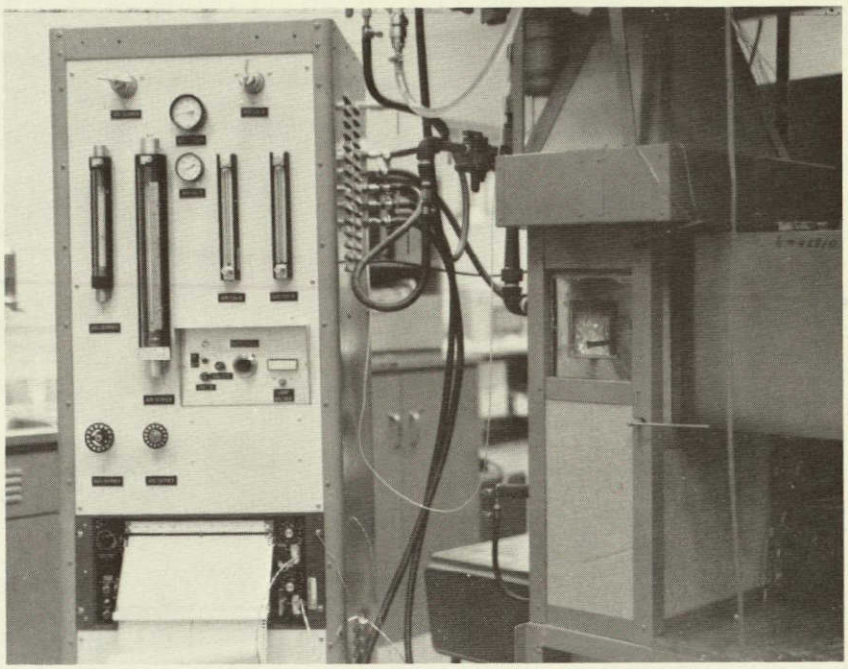


Figure 9.–Ohio State University Release Rate Apparatus

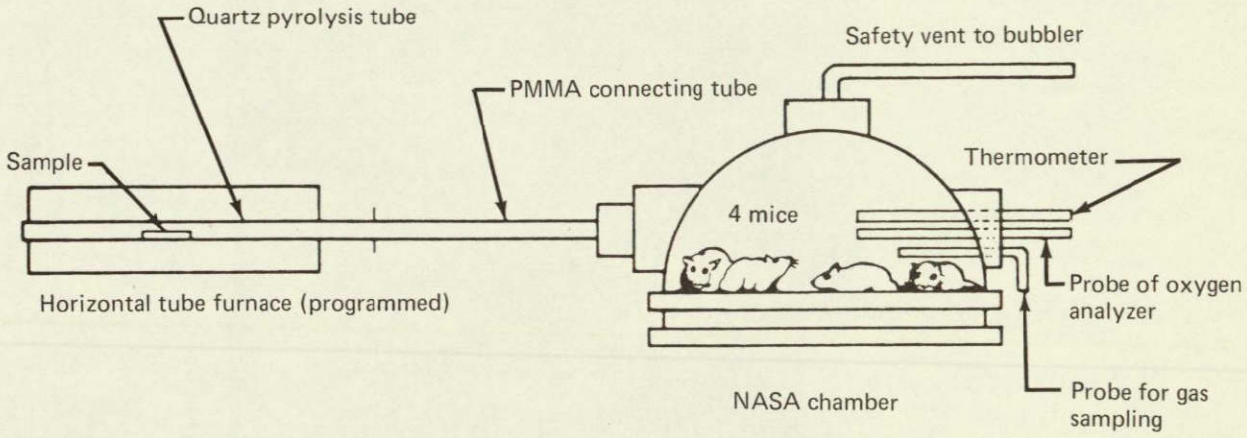


Figure 10.–NASA Animal Exposure Chamber

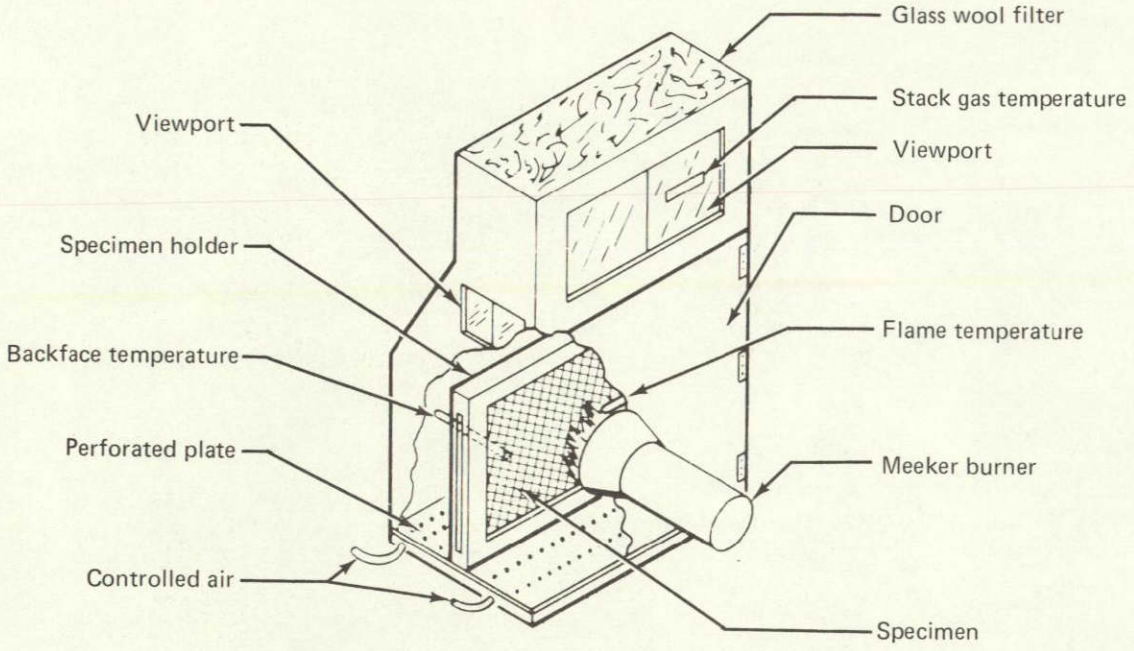


Figure 11.—Boeing Burn Through Apparatus

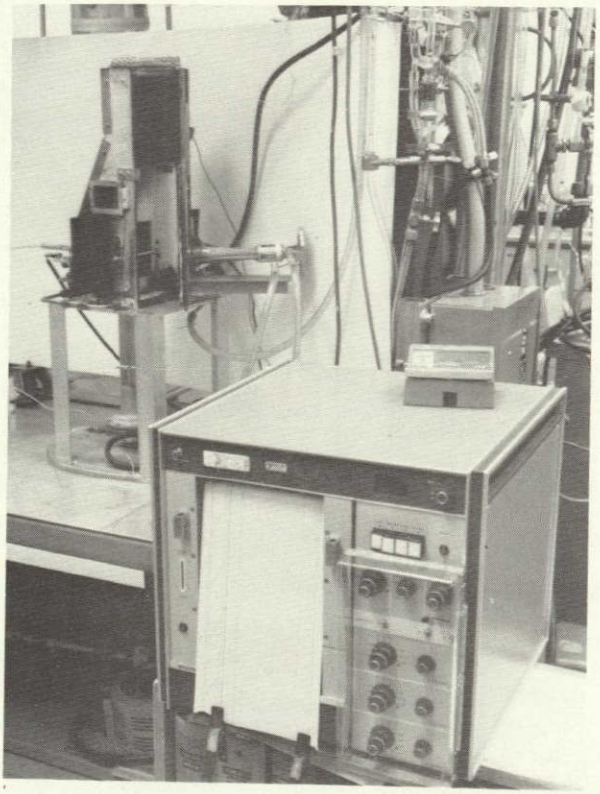


Figure 12.—Boeing Burn Through Apparatus Showing Instrumentation

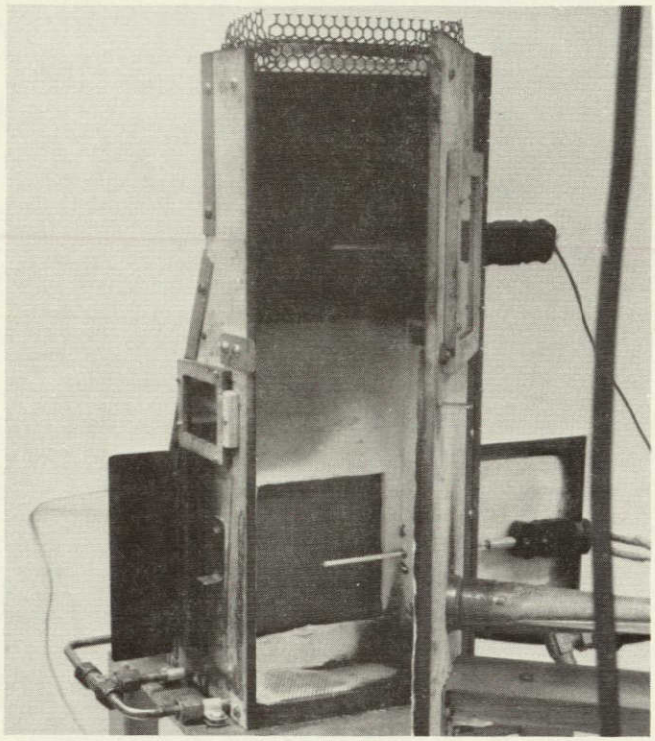


Figure 13.—Boeing Burn Through Test Chamber Showing Specimen Test Window

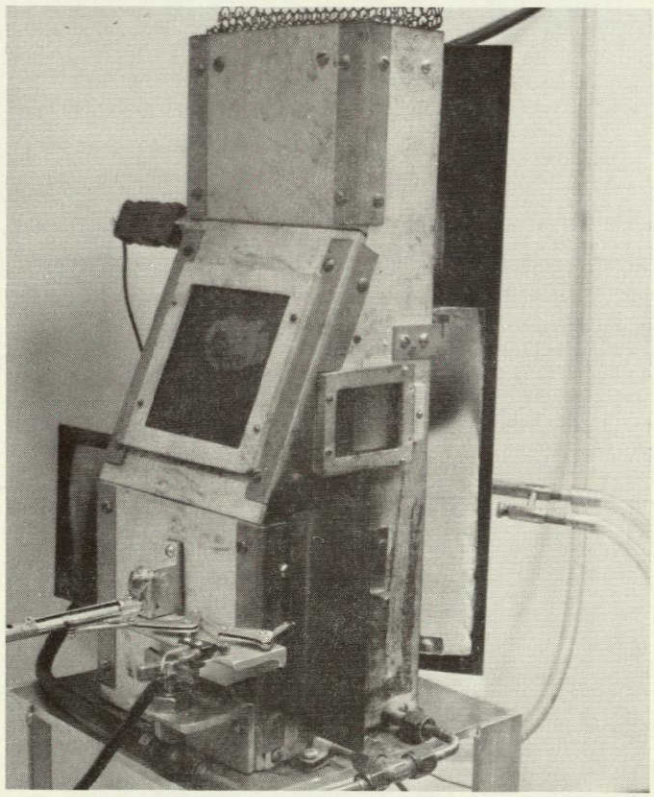


Figure 14.—Boeing Burn Through Test Apparatus Showing Operation of Backface Thermocouple Levers

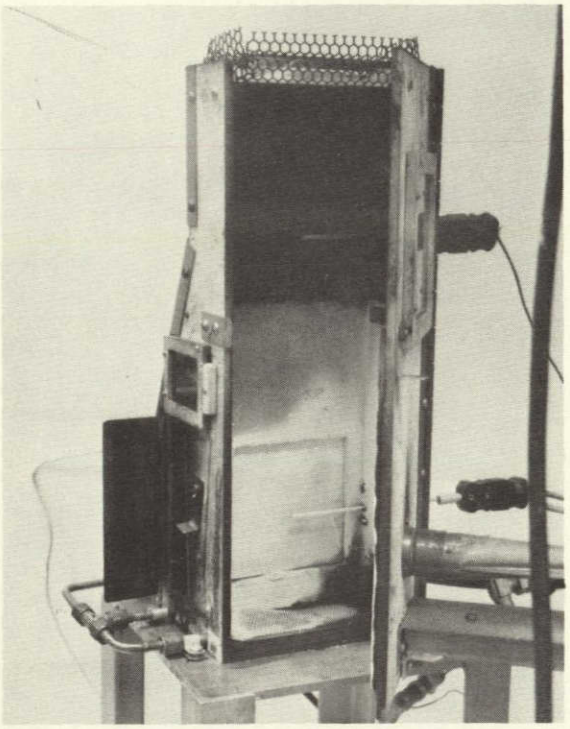


Figure 15.—Boeing Burn Through Test Apparatus Showing Baffle Positioned in Test Window Preparatory to Starting the Burner

	System 1
	FIBERITE MXB-7203
	FIBERITE MXB-7251
	3 PCF PHENOLIC/POLYAMIDE
	FIBERITE MXB-7251
	FIBERITE MXB-7251

Cure cycle

Precure 12 min, 6.9×10^5 N/m^2 (100 psi), 160°C (320°F)

Bond 60 min, 6.9×10^4 N/m^2 (10 psi), 127°C (260°F)

Figure 16.—Baseline System—Epoxy

	System 4	System 6	System 8	System 9
	DUPONT PYRALIN 3002	DUPONT PYRALIN 3002	DUPONT PYRALIN 3002	DUPONT PYRALIN 3002
	AM. CYANAMID BR-34	AM. CYANAMID BR-34	AM. CYANAMID BR-34	AM. CYANAMID BR-34
	4.5 PCF POLYIMIDE/ FIBERGLASS	4.5 PCF POLYIMIDE/ FIBERGLASS PLUS 2 PCF PI/PU FOAM	3 PCF POLYIMIDE/ POLYAMIDE	3 PCF POLYIMIDE/ POLYAMIDE PLUS 2 PCF PI/PU FOAM
	AM. CYANAMID BR-34	AM. CYANAMID BR-34	AM. CYANAMID BR-34	AM. CYANAMID BR-34
	DUPONT PYRALIN 3002	DUPONT PYRALIN 3002	DUPONT PYRALIN 3002	DUPONT PYRALIN 3002

Cure cycle
Precure: 60 min, $6.9X10^4 N/m^2$, (10 psi), 177° C (350° F)

Bond: 60 min, $6.9X10^4 N/m^2$, (10 psi), 177° C (350° F)

Figure 19.—Experimental Sandwich Systems — Polyimides

	Baseline Film 1	Flame Modified Tedlar Film 2	Fluorex H Film 3	Polycarbonate Film 4	Polyethersulfone Film 5
Protective film	0.025mm (0.001 in) CLEAR PVF	0.025mm (0.001 in) CLEAR PVF	0.038mm (0.0015 in) CLEAR PVF_2	0.025mm (0.001 in) CLEAR PVF	0.025mm (0.001 in) CLEAR PVF
Decorative ink	ACRYLIC INK	ACRYLIC INK	ACRYLIC INK	ACRYLIC INK	ACRYLIC INK
Substrate film	0.051mm (0.002 in) WHITE PVF	0.025mm (0.001 in) FM-PVF	0.051mm (0.002 in) WHITE PVF_2	0.127mm (0.005 in) WHITE PC	0.127mm (0.005 in) CLEAR PES

Figure 20.—Decorative Film Systems

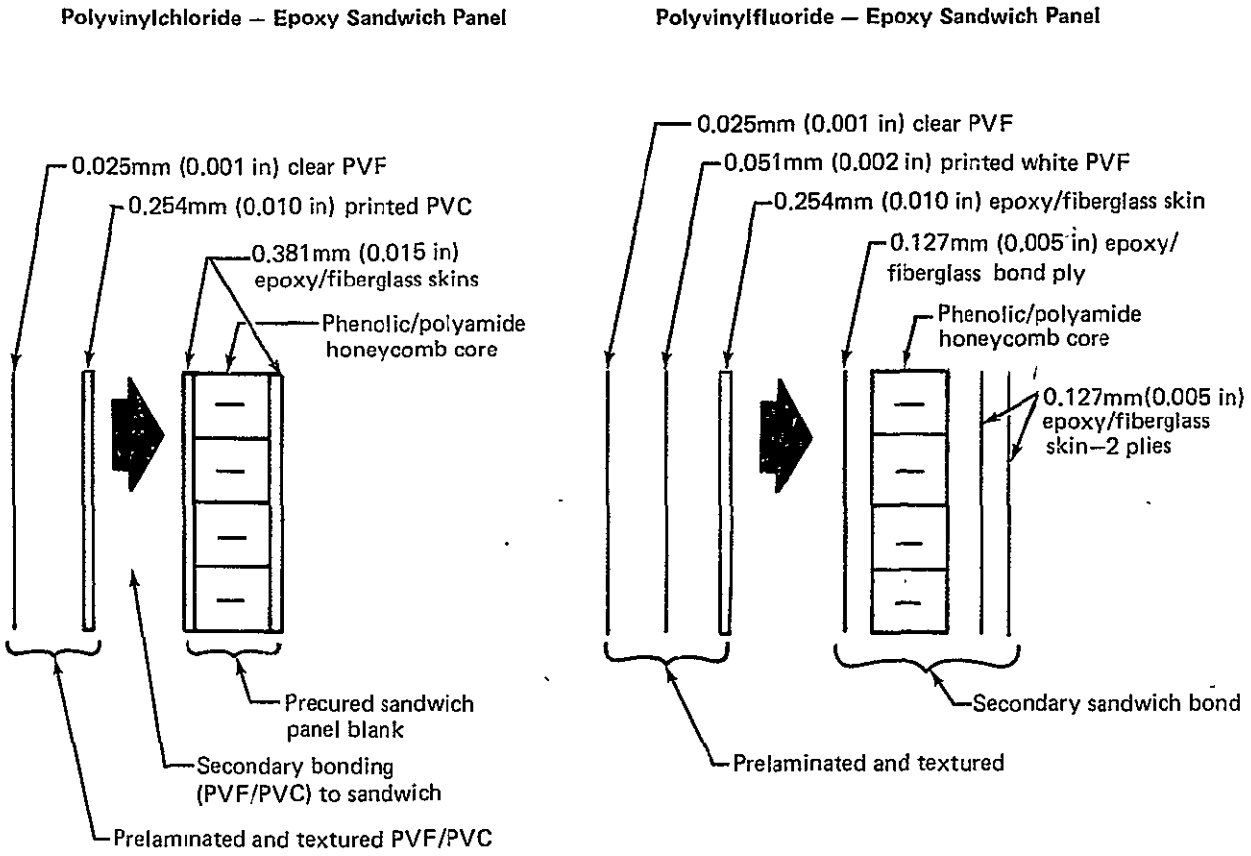


Figure 21.–Baseline Sandwich Panels

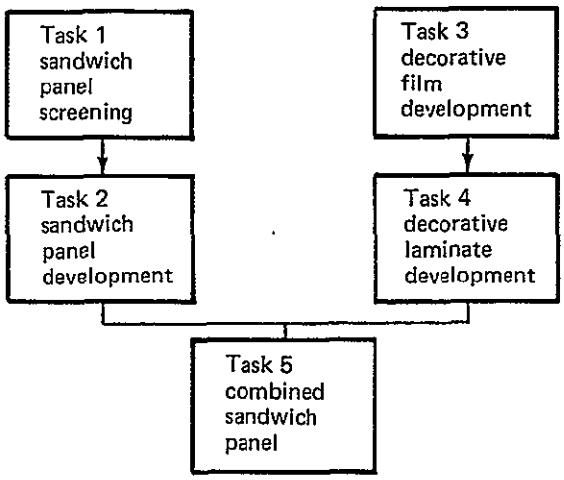


Figure 22.–Summary of Program Tasks

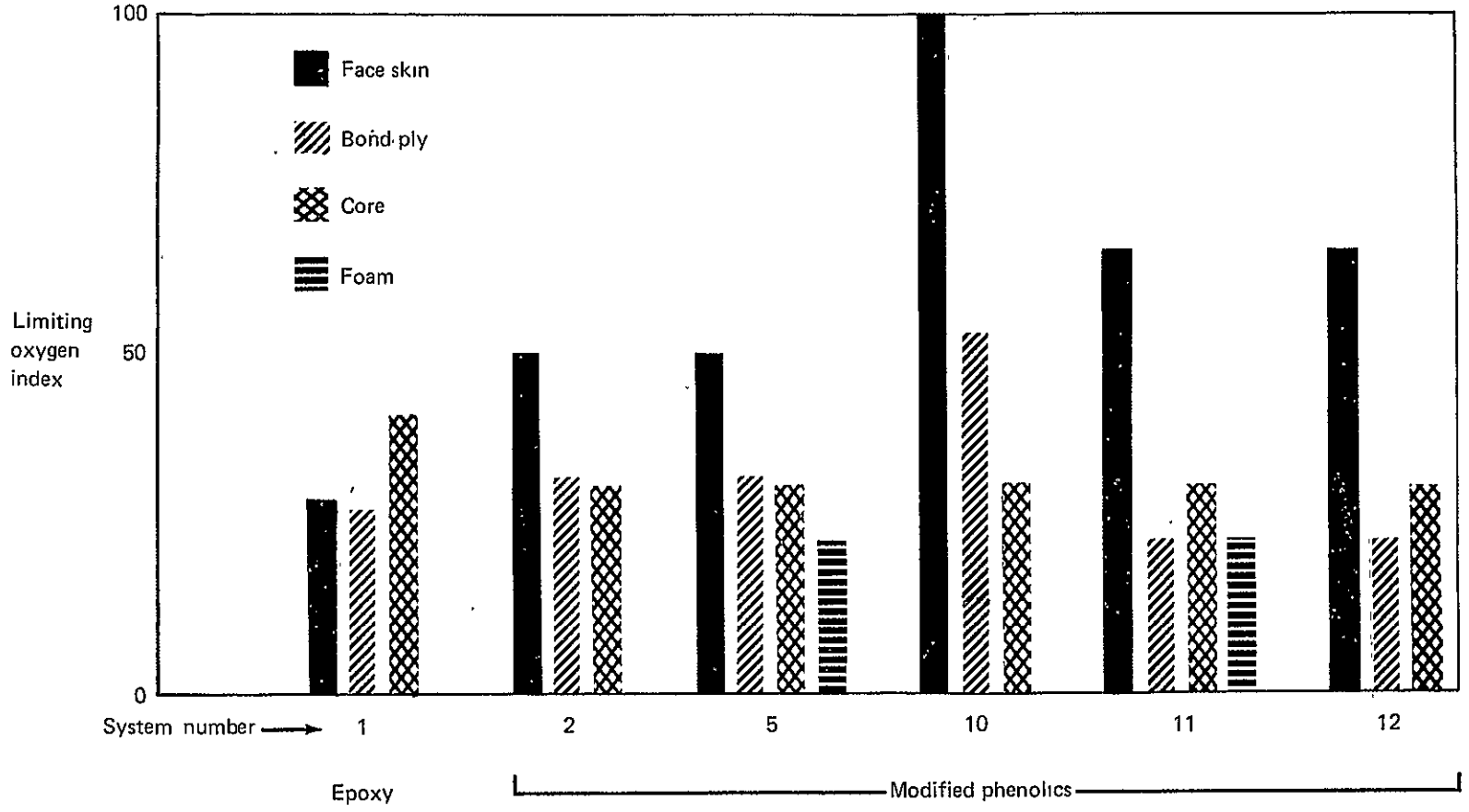


Figure 23.—Limiting Oxygen Index — Phenolics — Task 2

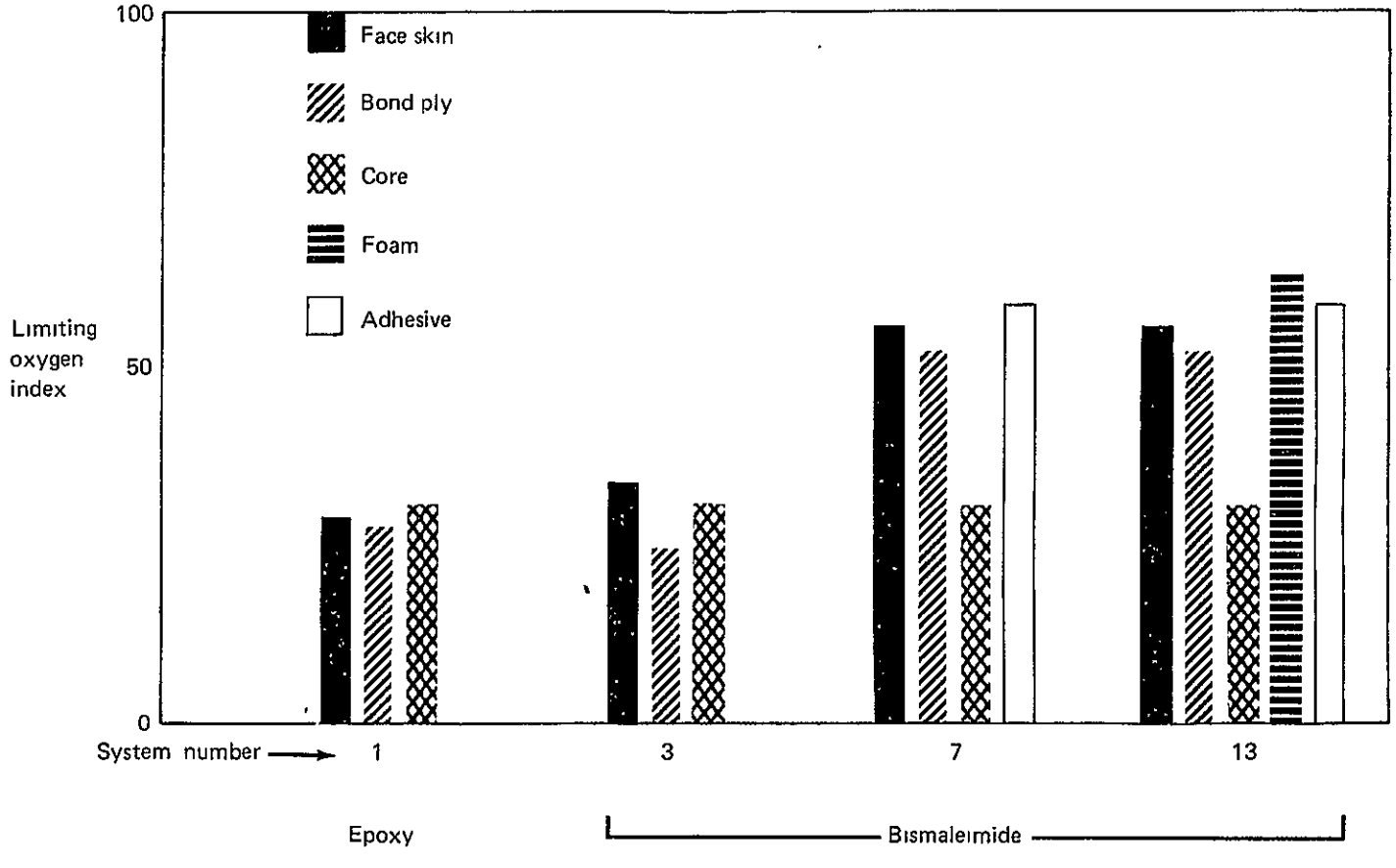


Figure 24.—Limiting Oxygen Index — Bismaleimides — Task 2

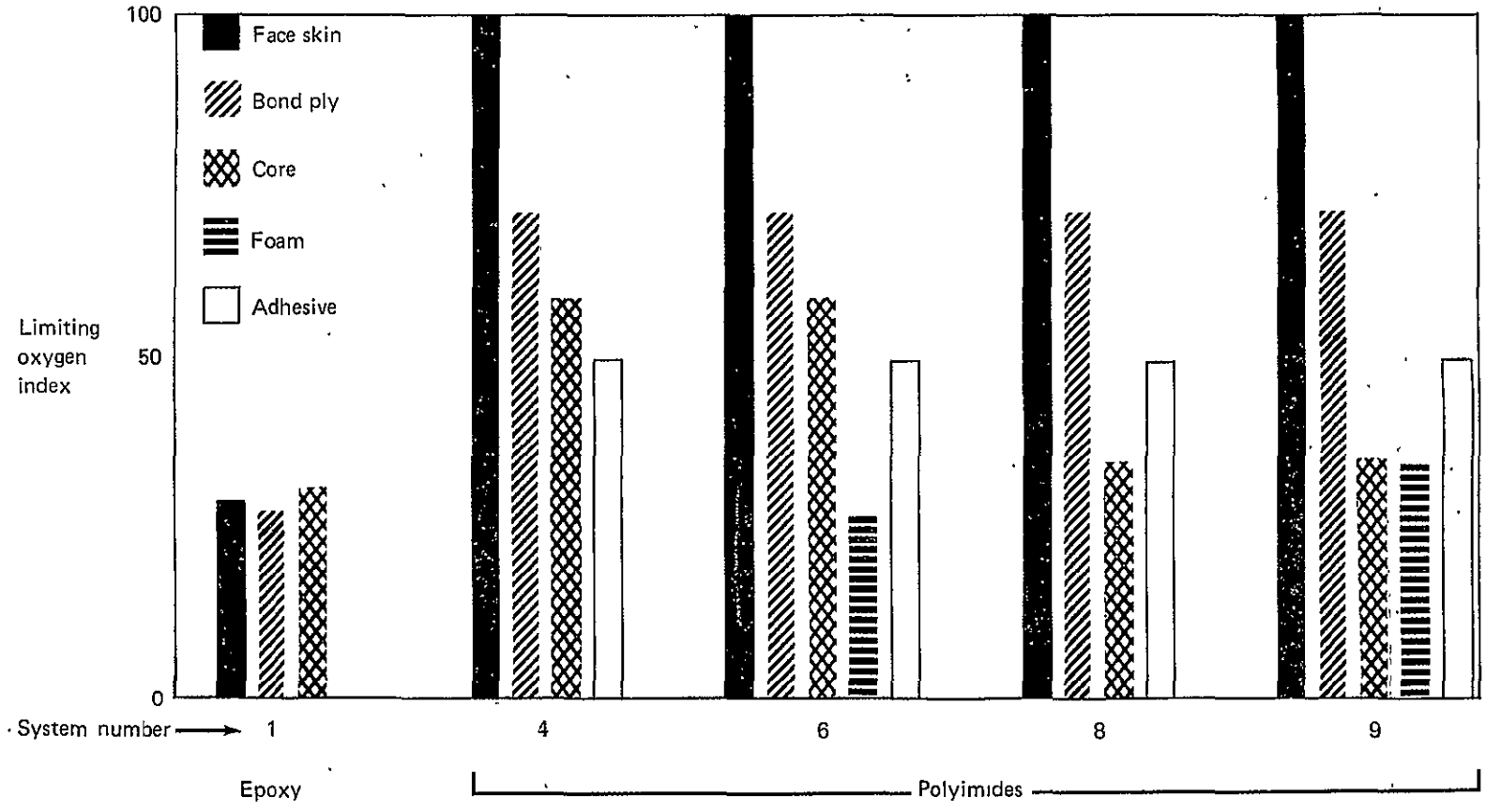


Figure 25.—Limiting Oxygen Index — Polyimides — Task 2

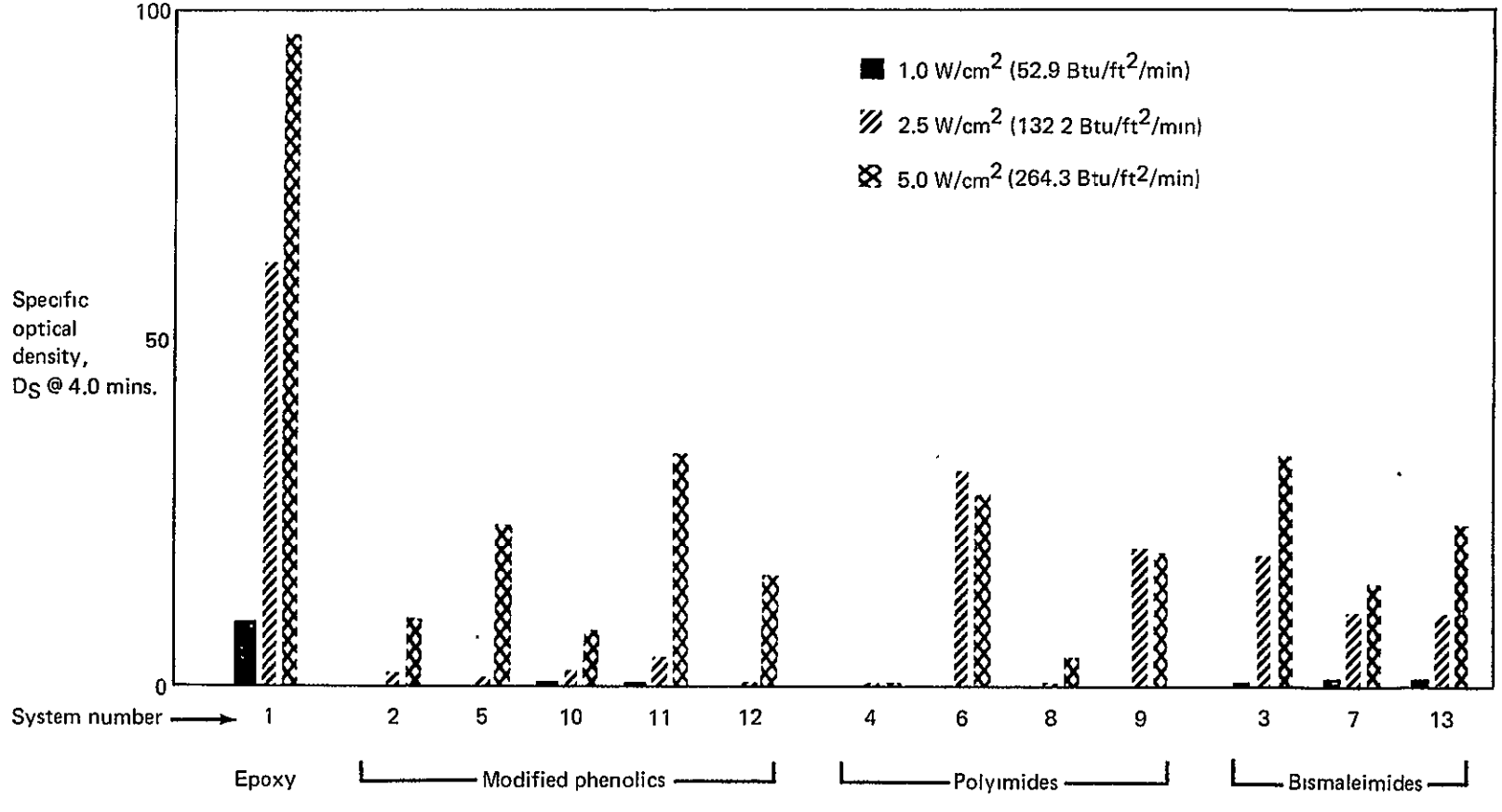


Figure 26.—Smoke Emission as Measured in the NBS Smoke Chamber — D_S — Task 2

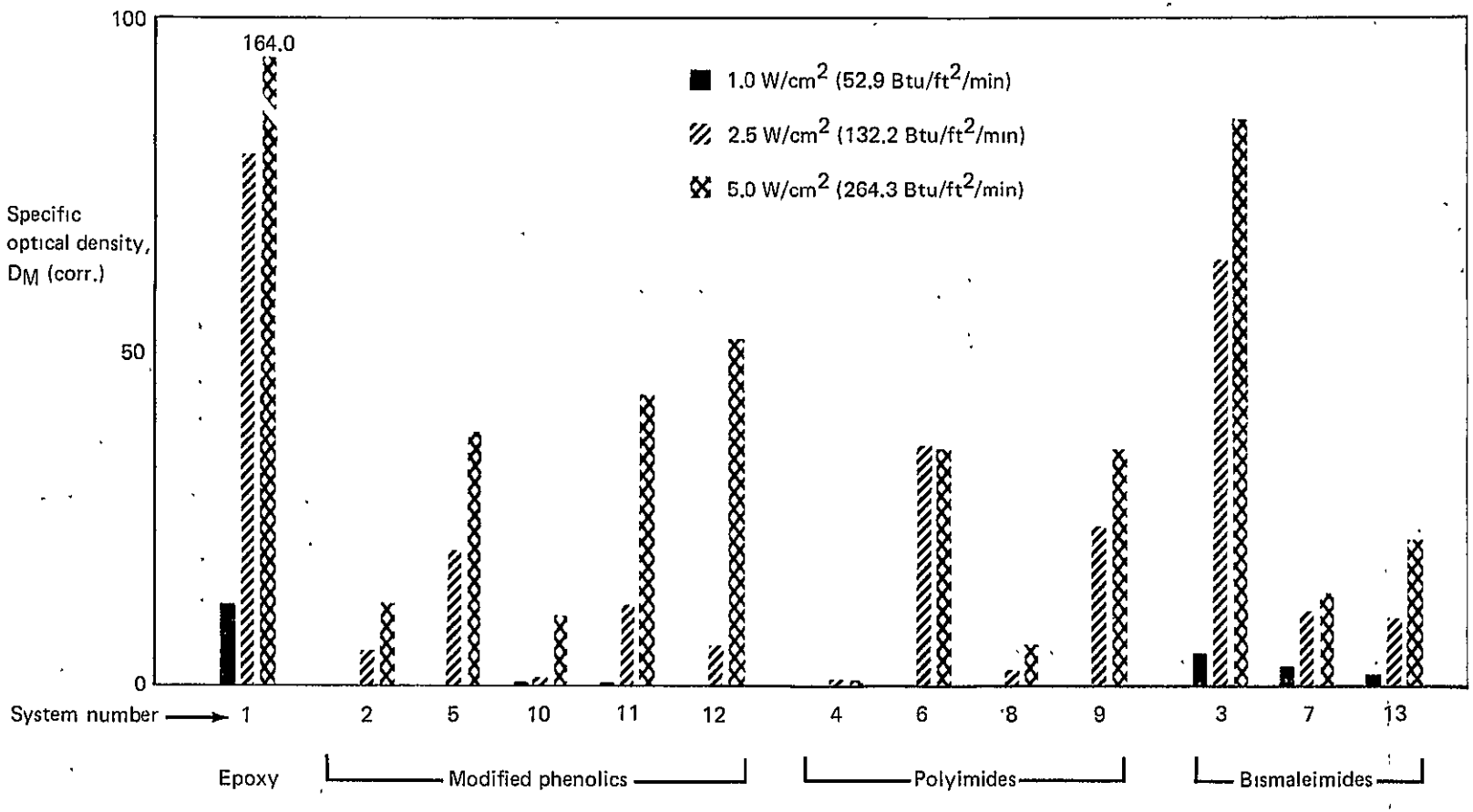


Figure 27.—Smoke Emission as Measured in the NBS Smoke Chamber — D_M — Task 2

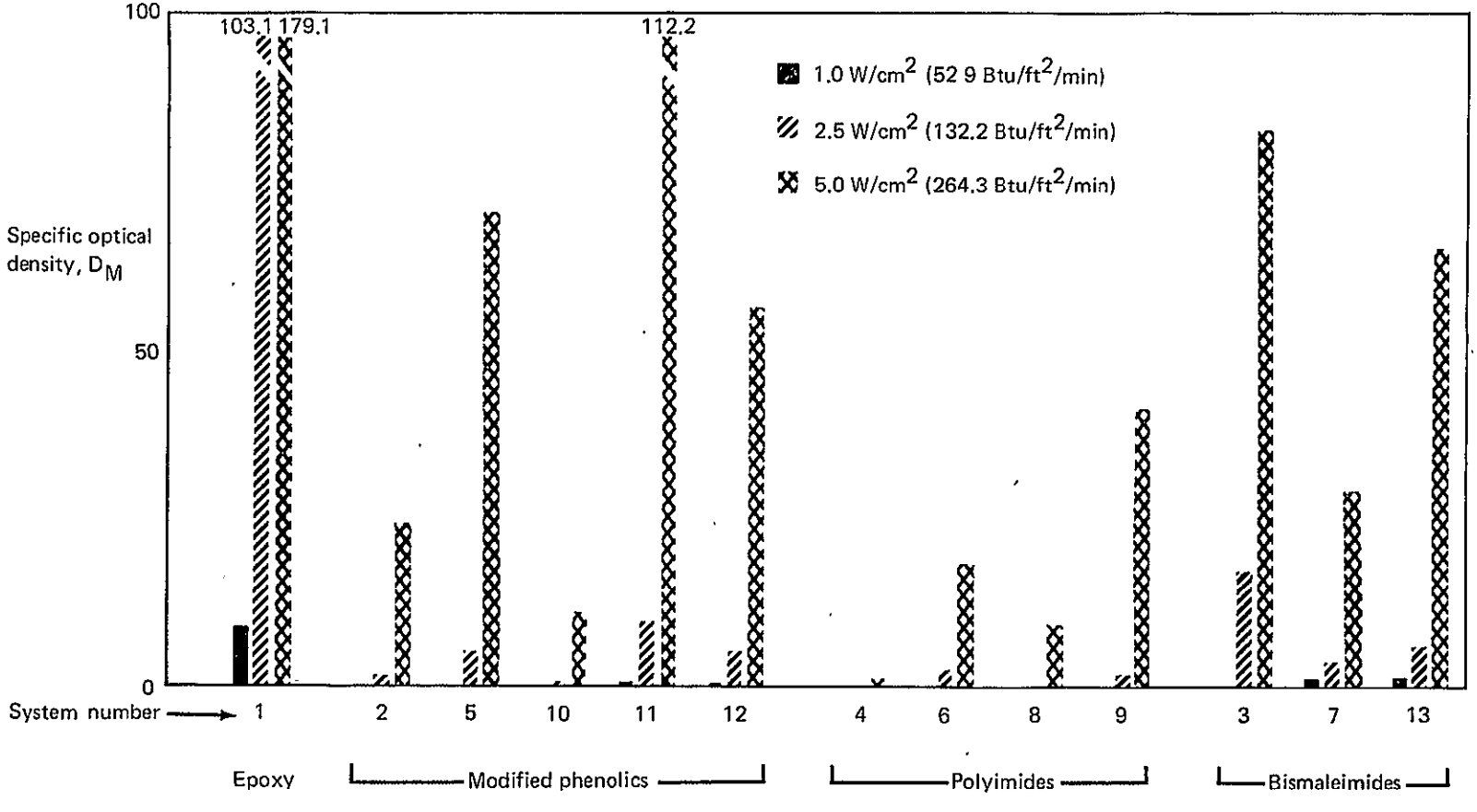


Figure 28.—Smoke Emission as Measured in the OSU Release Rate Apparatus — Vertical Flaming — D_M — Task 2

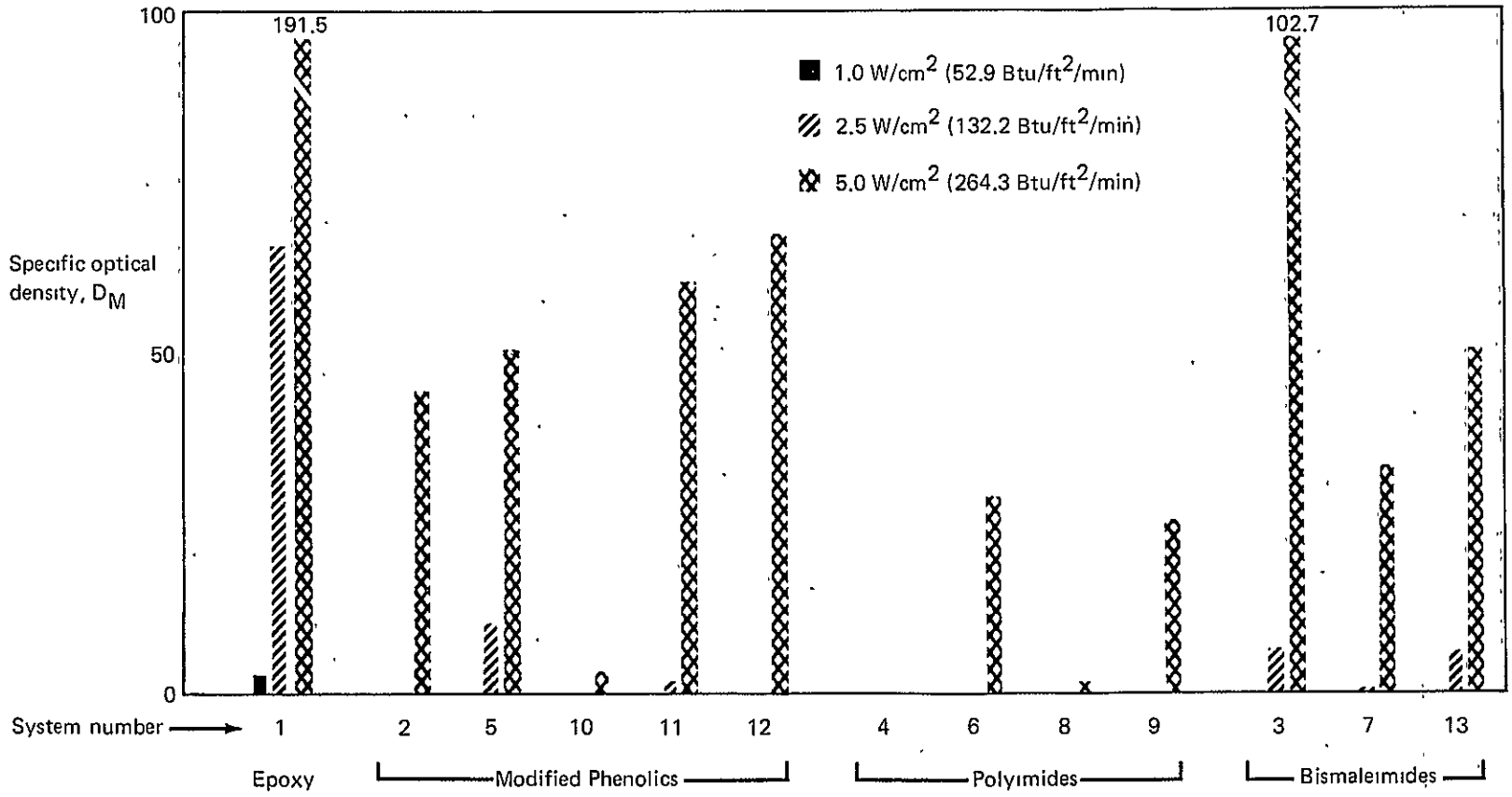


Figure 29.—Smoke Emission as Measured in the OSU Release Rate Apparatus — Horizontal Flaming — D_M — Task 2

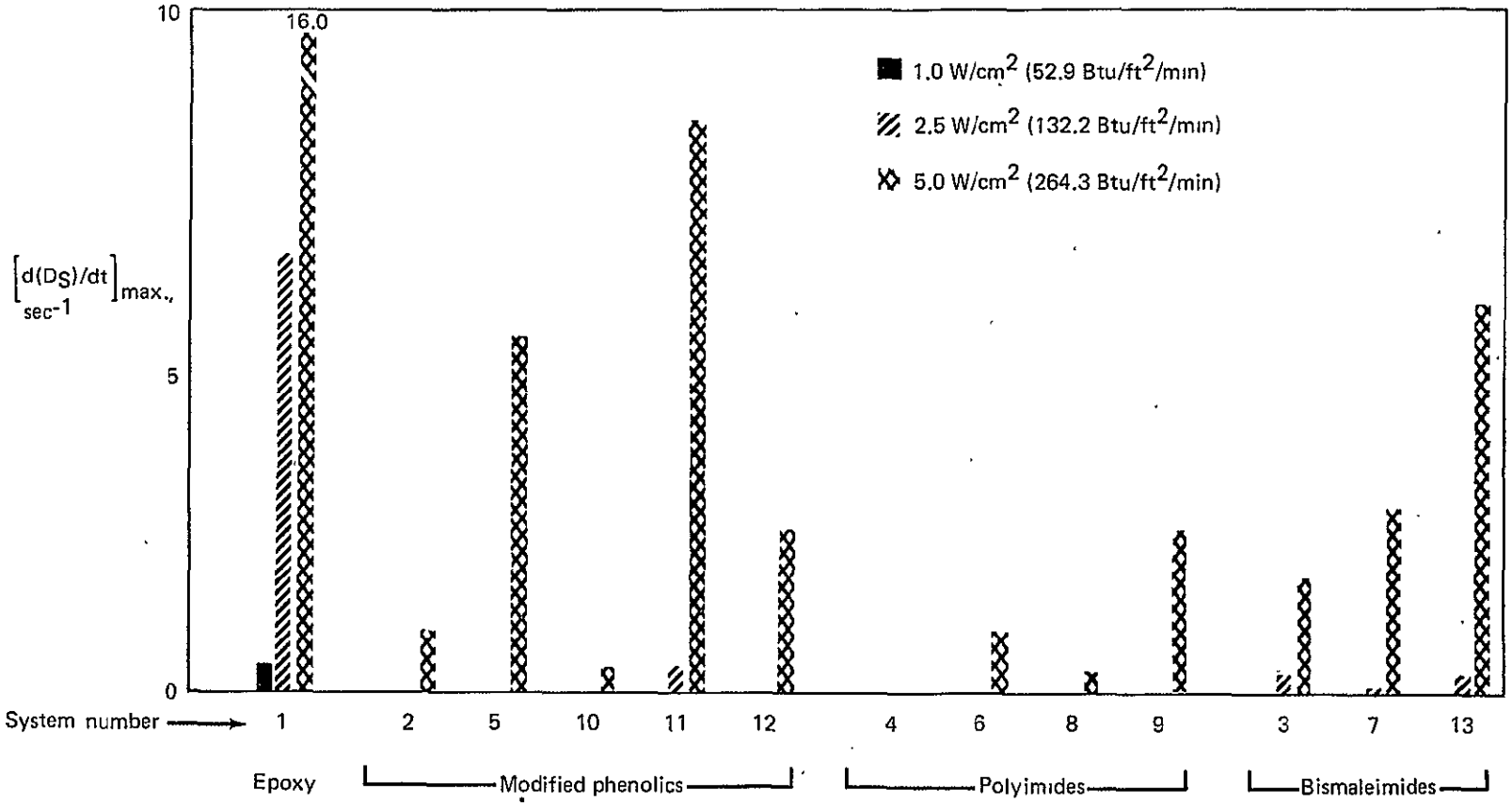


Figure 30.–Maximum Rate of Smoke Emission as Measured in the OSU Release Rate Apparatus — Vertical Flaming — Task 2

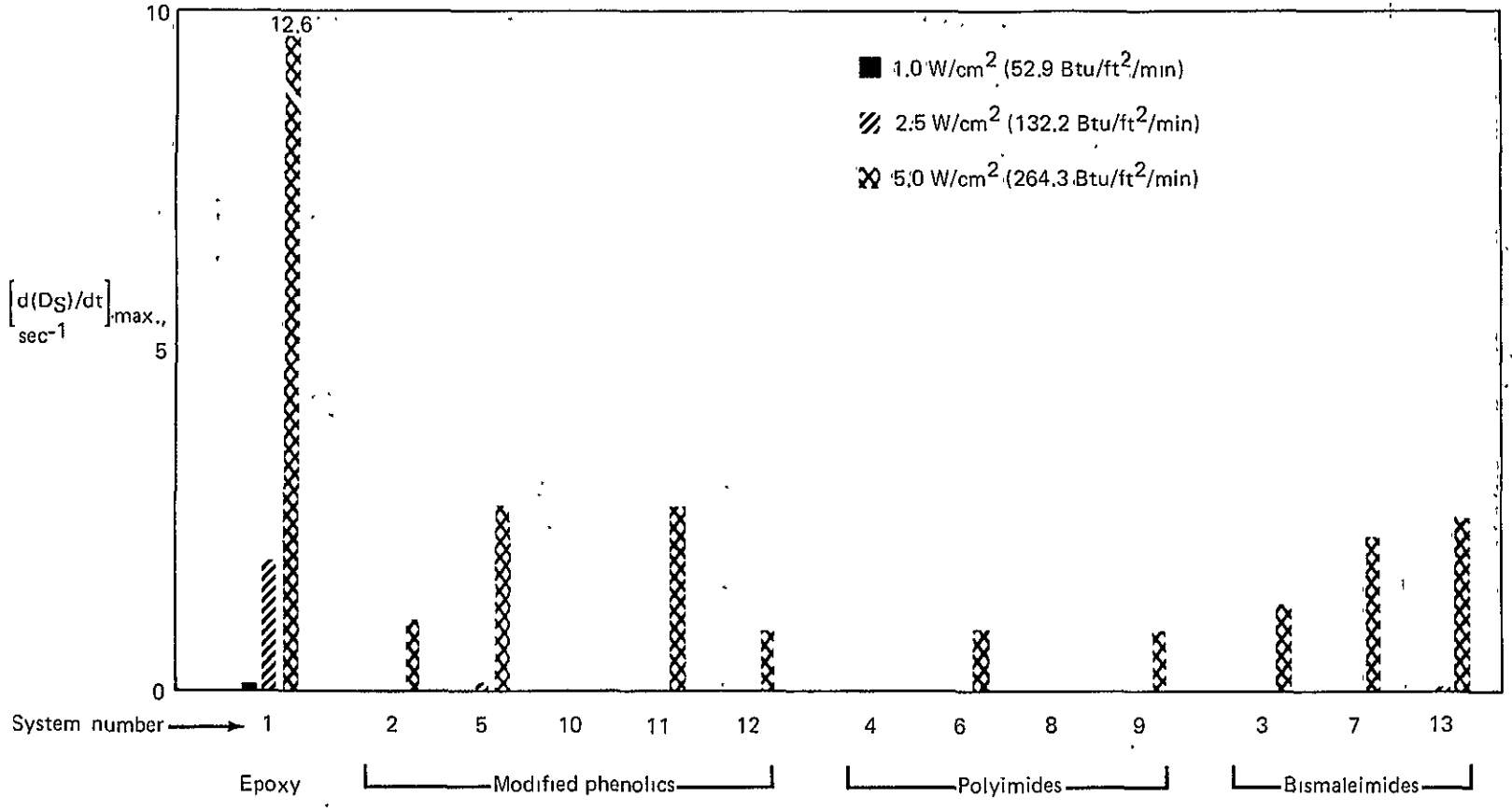


Figure 31.—Maximum Rate of Smoke Emission as Measured in the OSU Release Rate Apparatus – Horizontal Flaming – Task 2

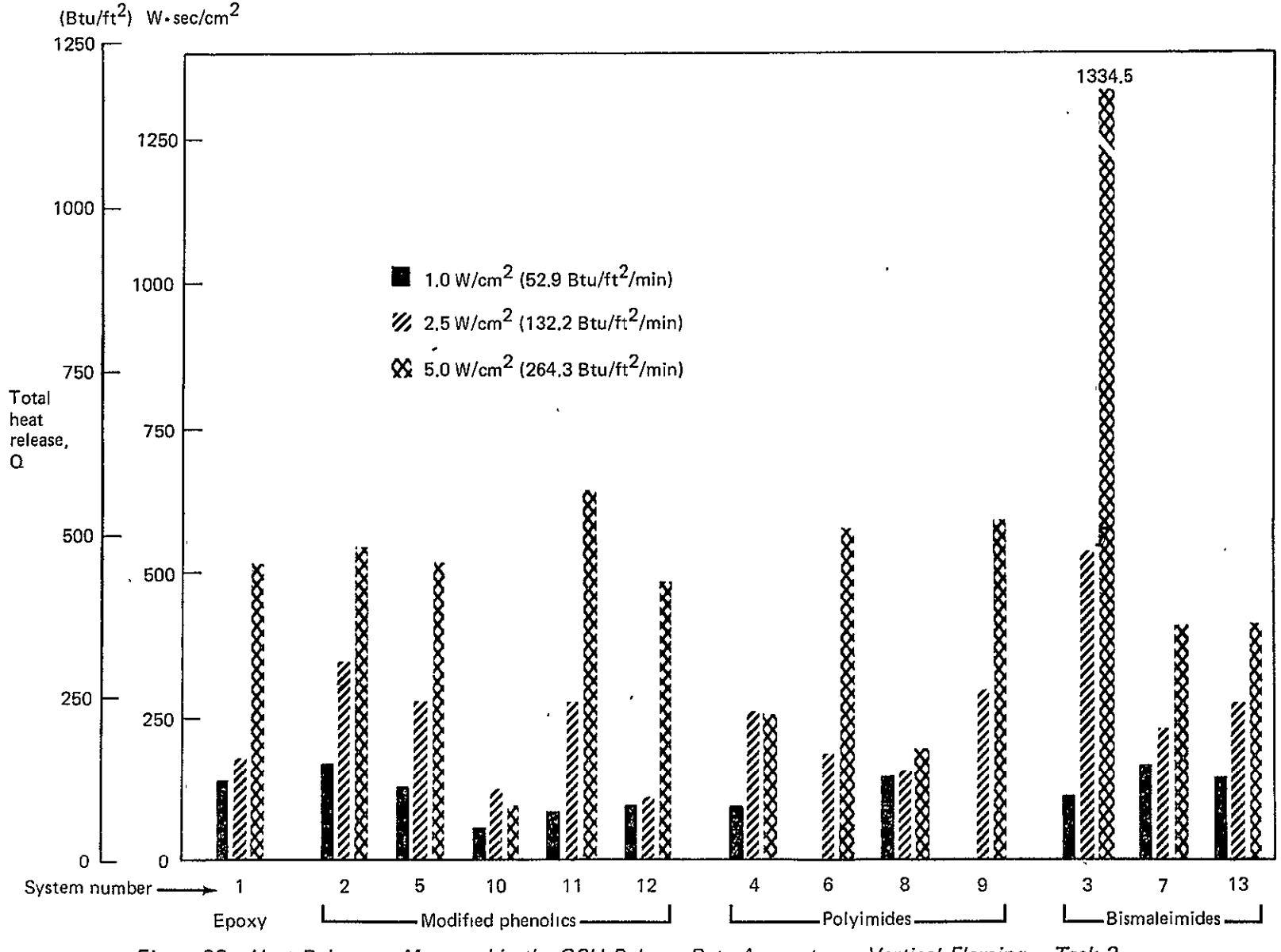


Figure 32.—Heat Release as Measured in the OSU Release Rate Apparatus — Vertical Flaming — Task 2

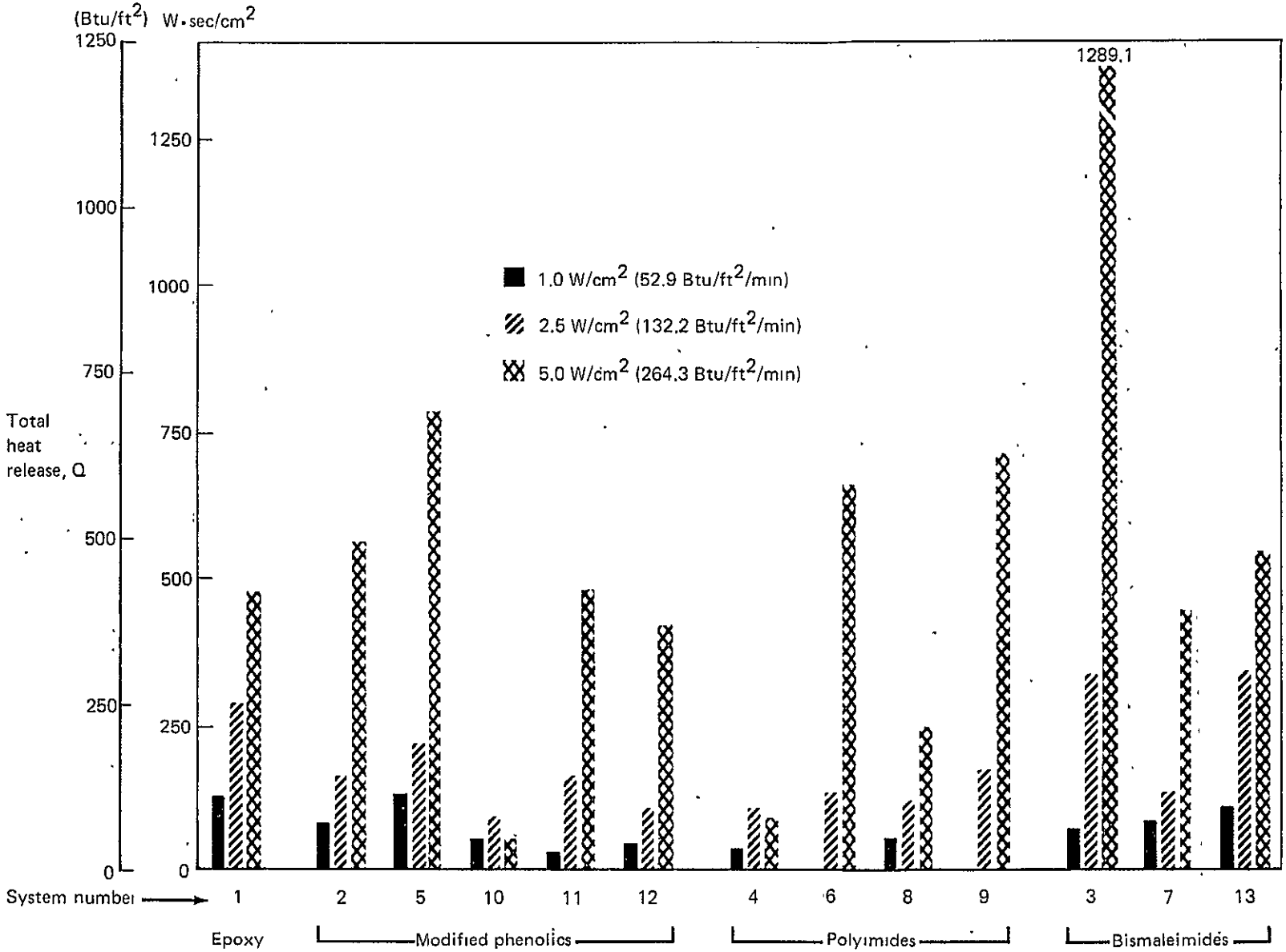


Figure 33.—Heat Release as Measured in the OSU Release Rate Apparatus — Horizontal Flaming — Task 2

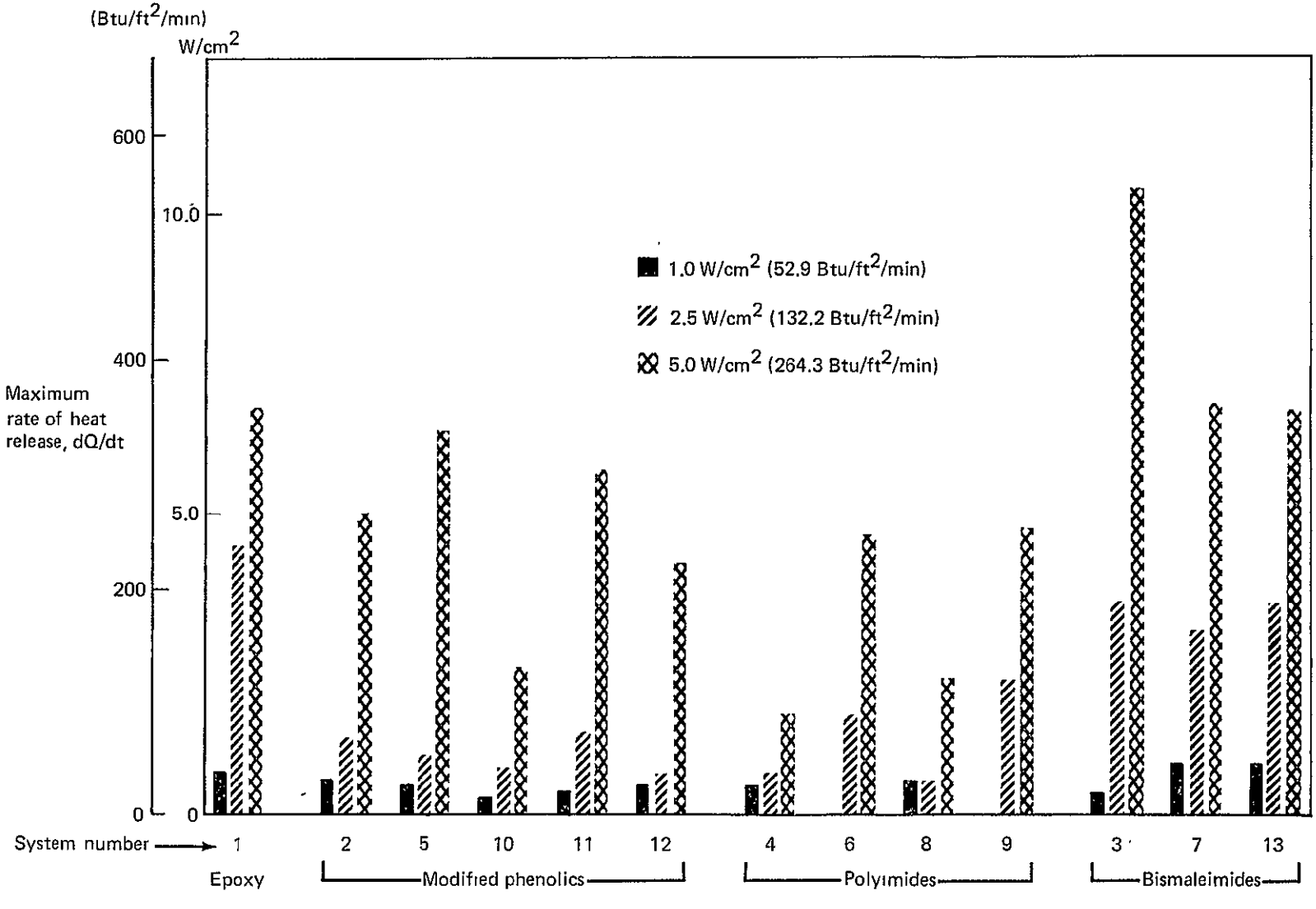


Figure 34.—Heat Release Rate as Measured in the OSU Release Rate Apparatus — Vertical Flaming — Task 2

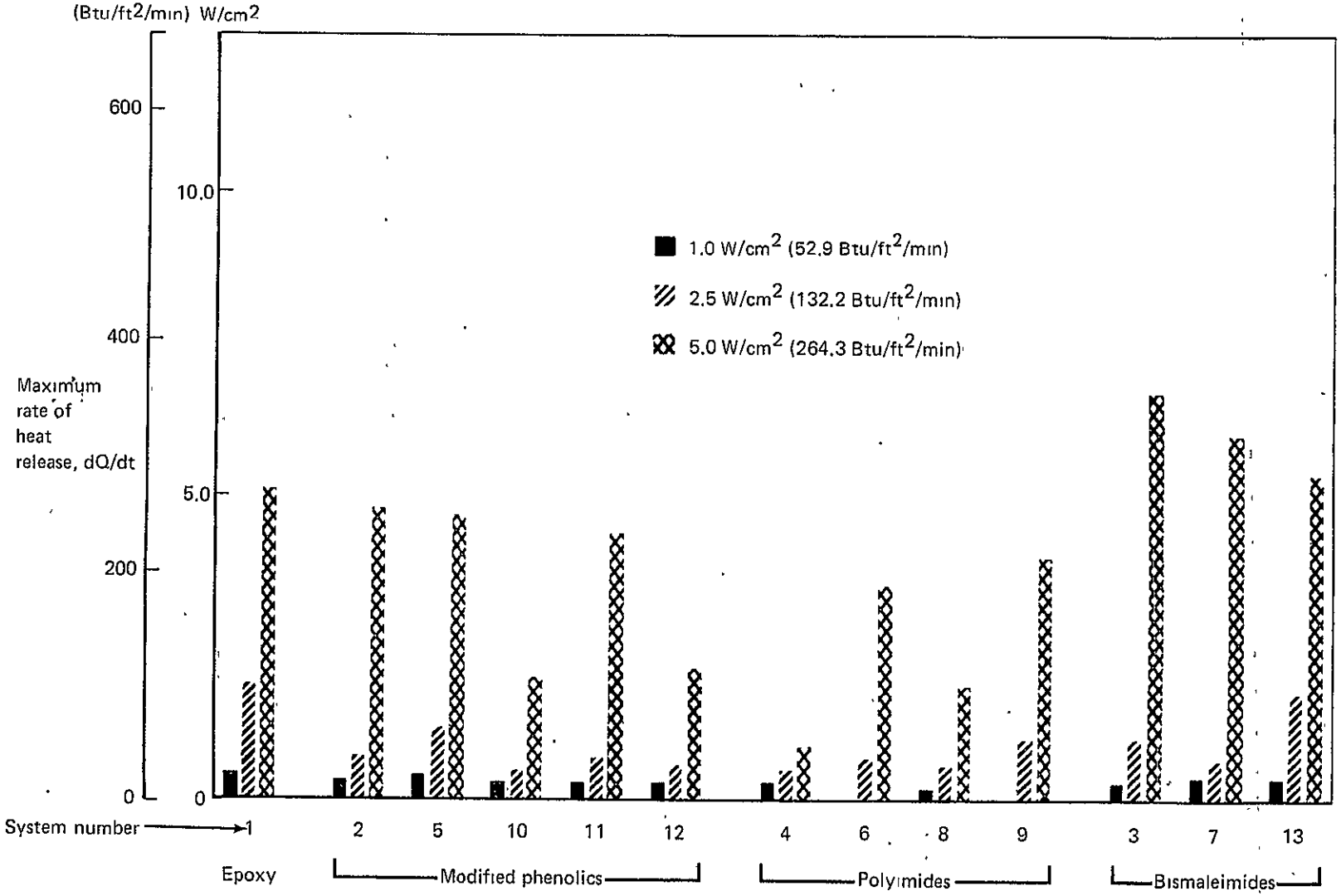


Figure 35.—Heat Release Rate as Measured in the OSU Release Rate Apparatus — Horizontal Flaming — Task 2

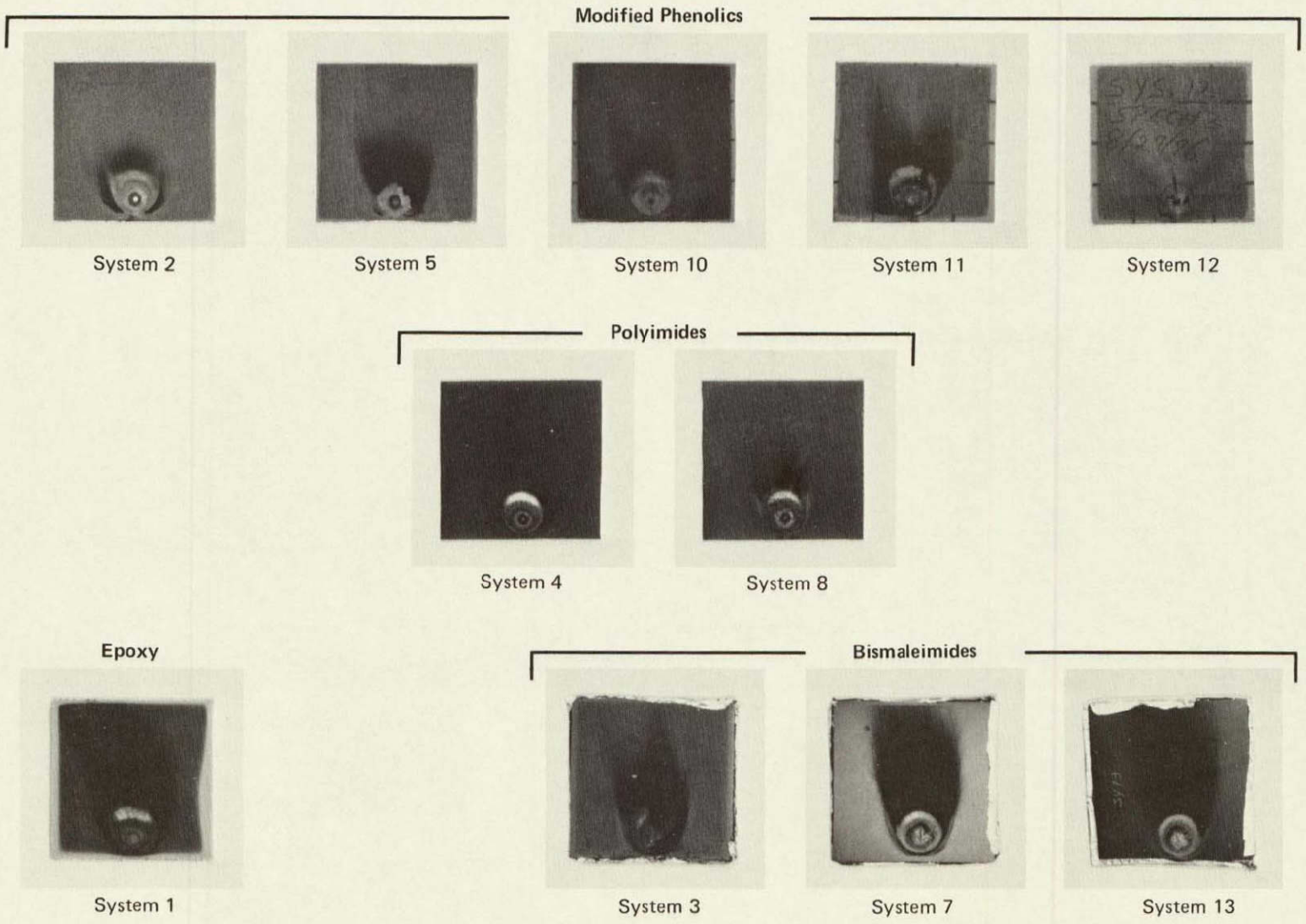


Figure 36.—OSU Heat Release Test Specimens—Vertical—1.0 W/cm^2 (Task 2)

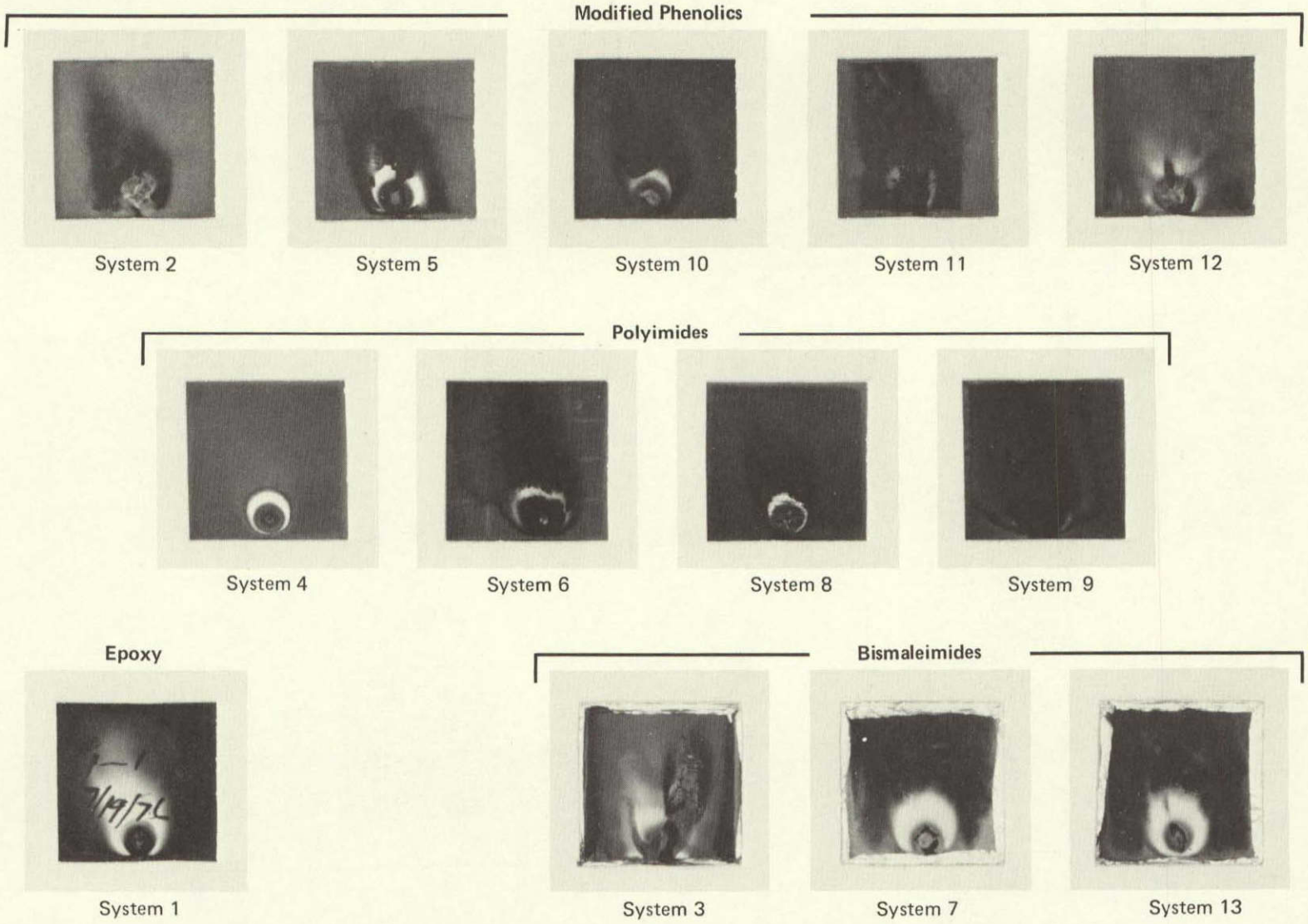


Figure 37.—OSU Heat Release Test Specimens—Vertical—2.5 W/cm^2 (Task 2)

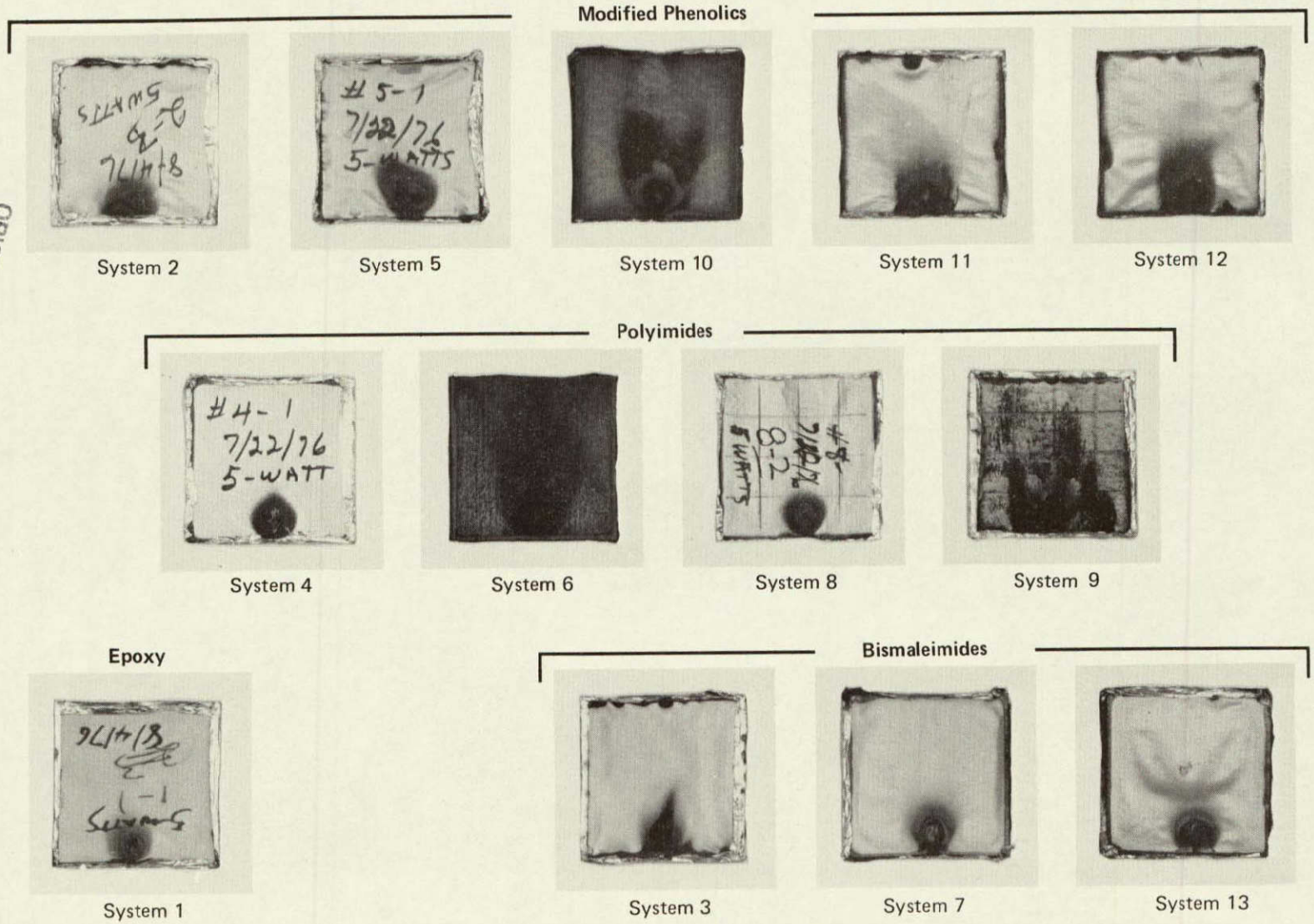


Figure 38.—OSU Heat Release Test Specimens — Vertical — 5.0 W/cm^2 (Task 2)

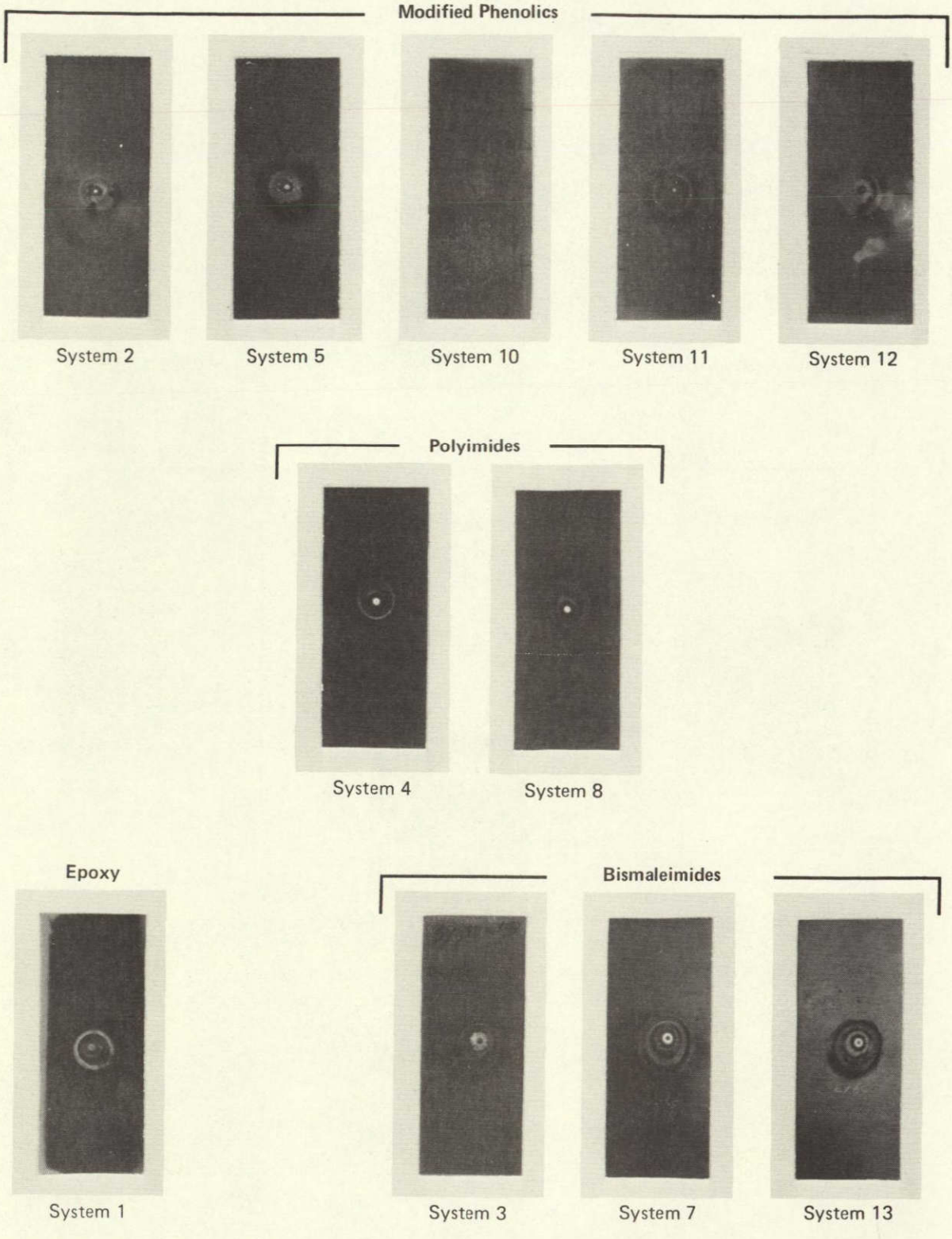


Figure 39.—OSU Heat Release Test Specimens—Horizontal—1.0 W/cm^2 (Task 2)

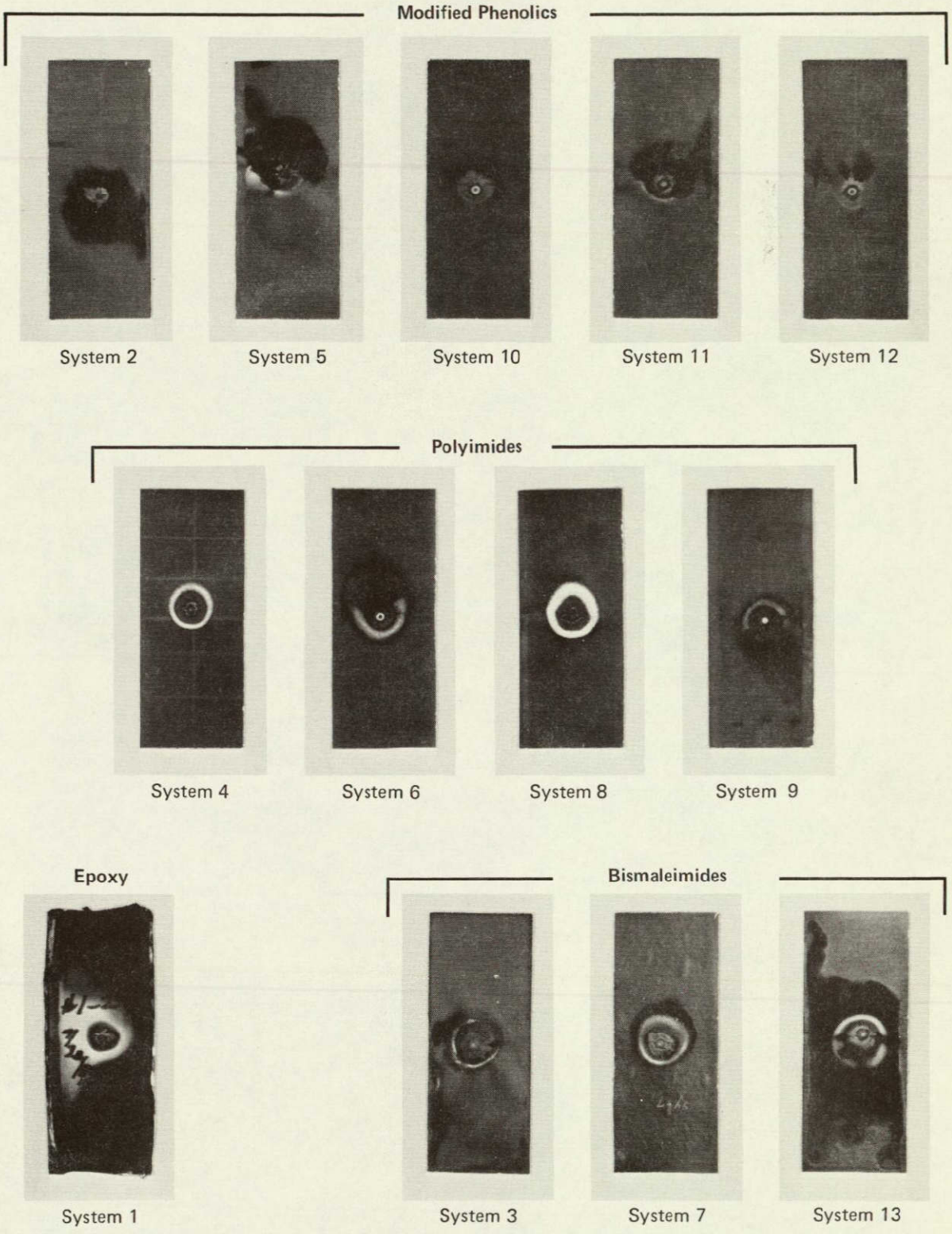


Figure 40.—OSU Heat Release Test Specimens—Horizontal—2.5 W/cm^2 (Task 2)

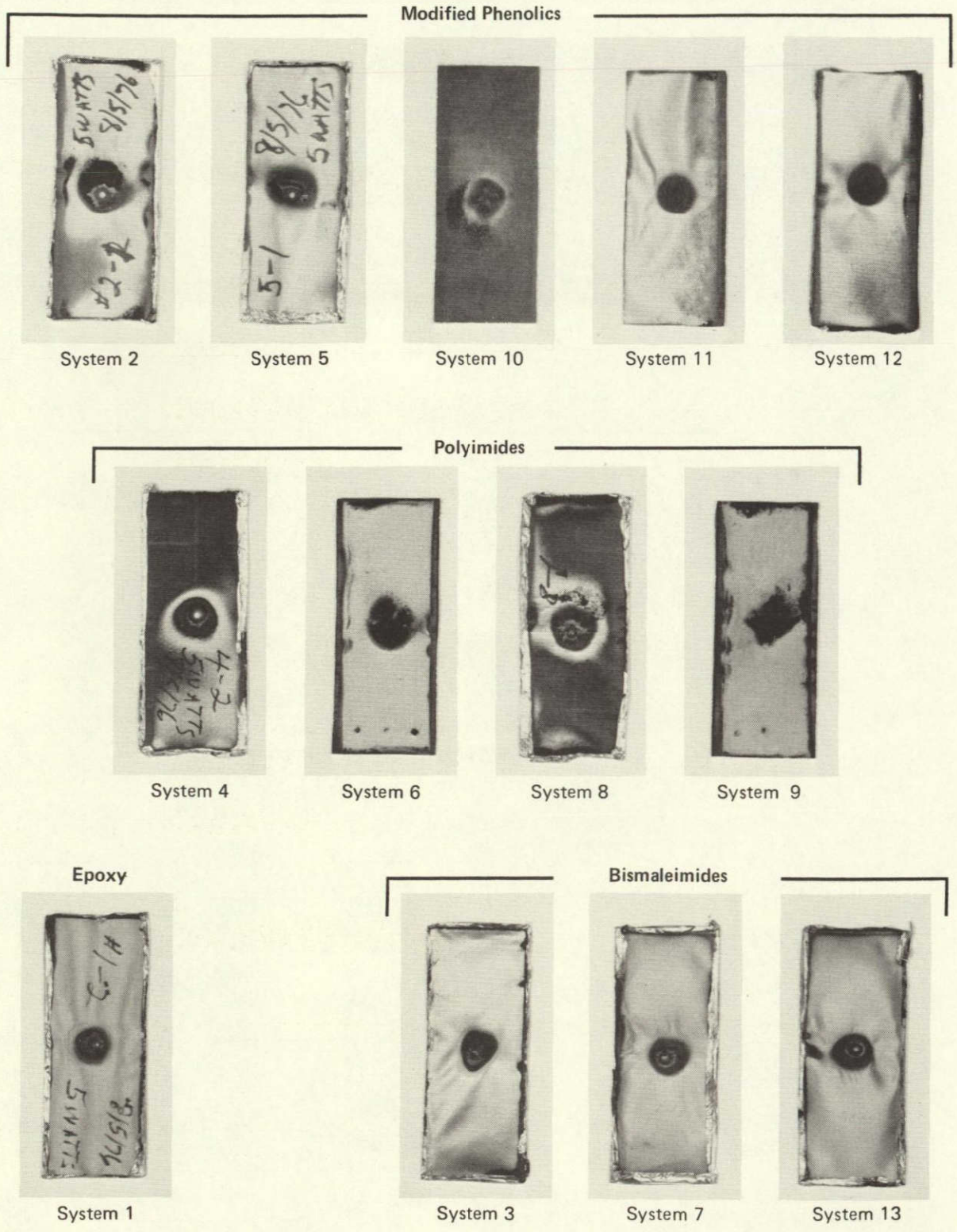


Figure 41.—OSU Heat Release Test Specimens—Horizontal—5.0 W/cm^2 (Task 2)

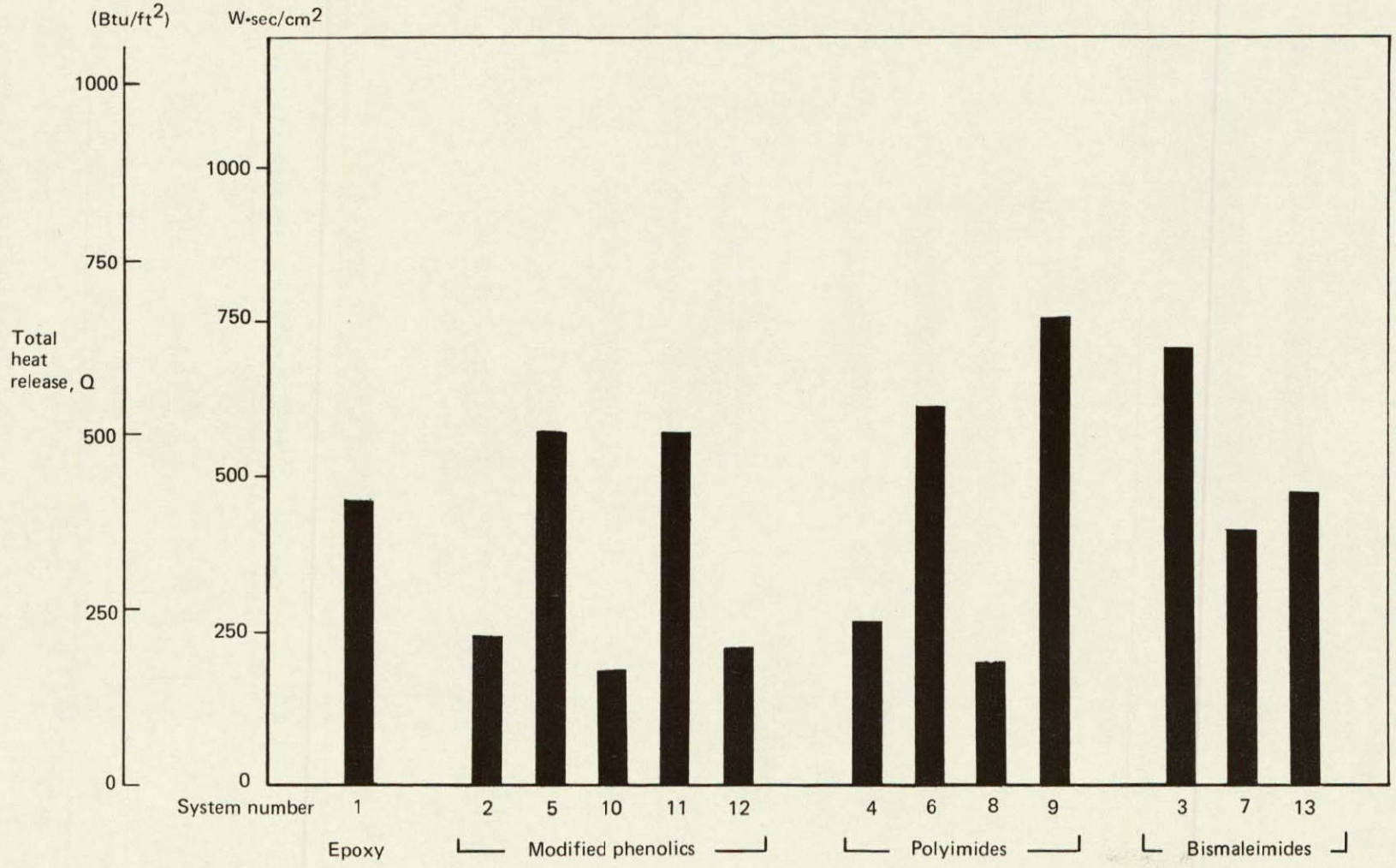


Figure 42.—Heat Release as Measured in the Boeing Burn Through Apparatus — Task 2

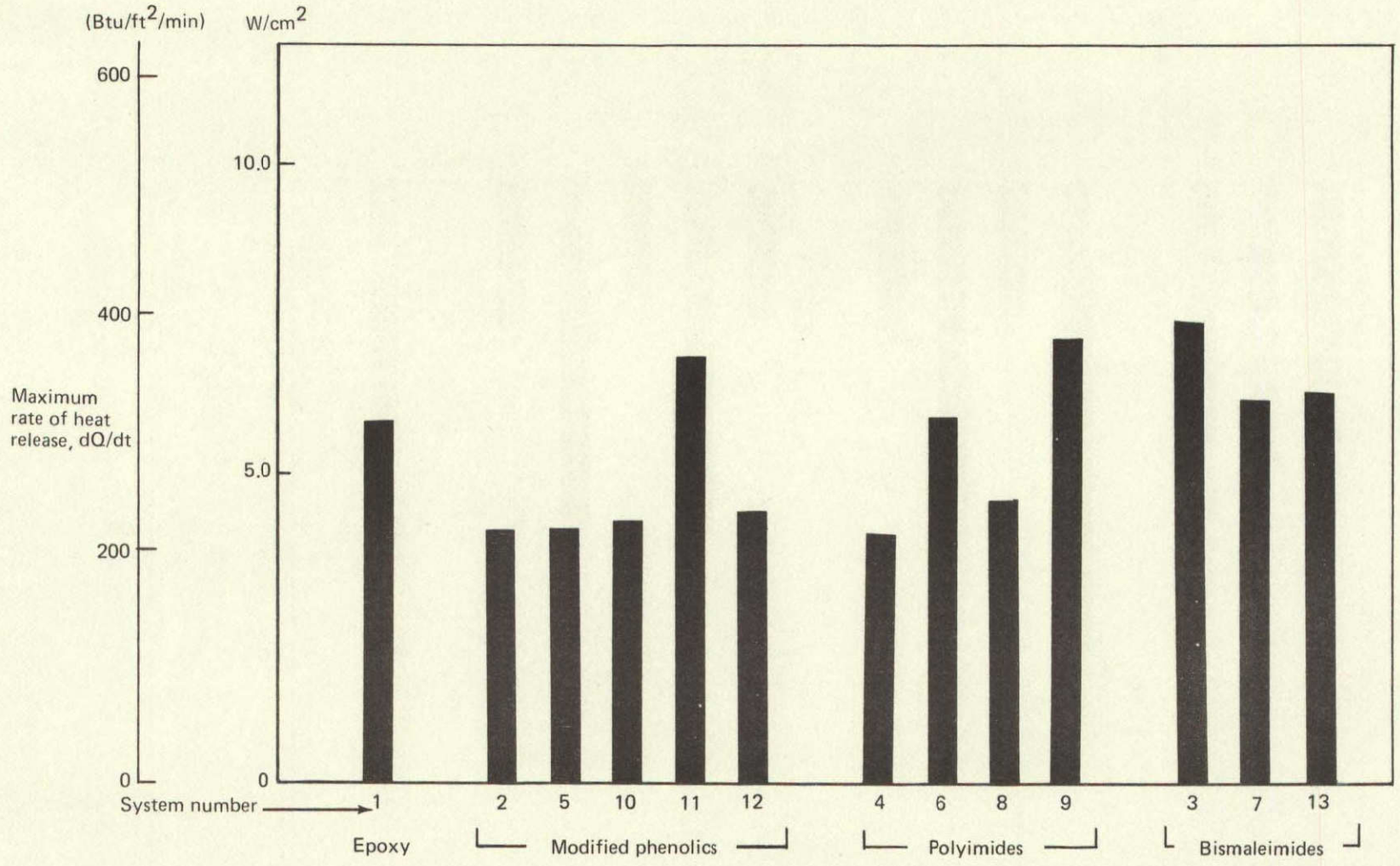


Figure 43.—Heat Release Rate as Measured in the Boeing Burn Through Apparatus — Task 2

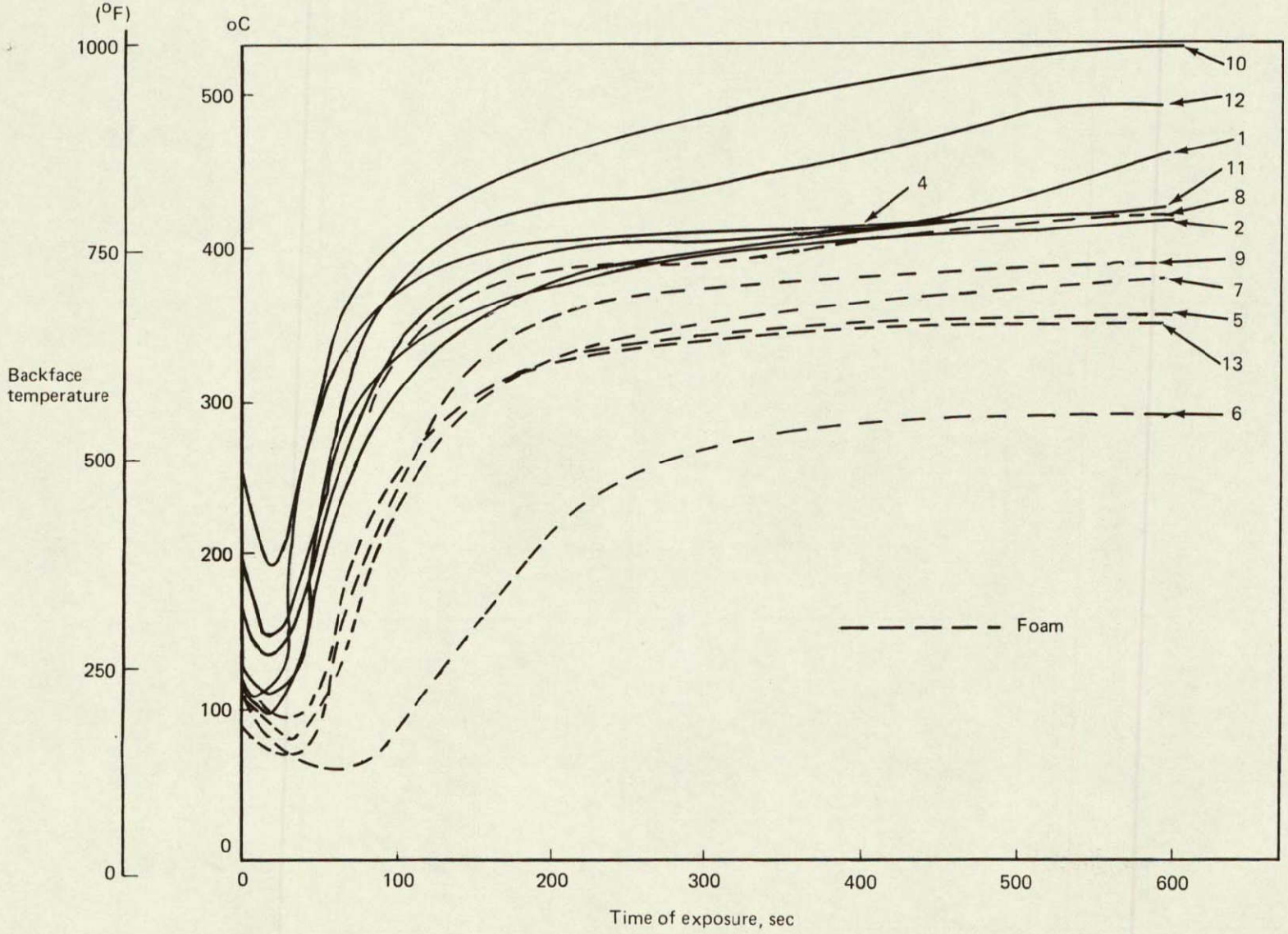


Figure 44.–Backface Temperature Versus Time – Boeing Burn Through Apparatus – Task 2

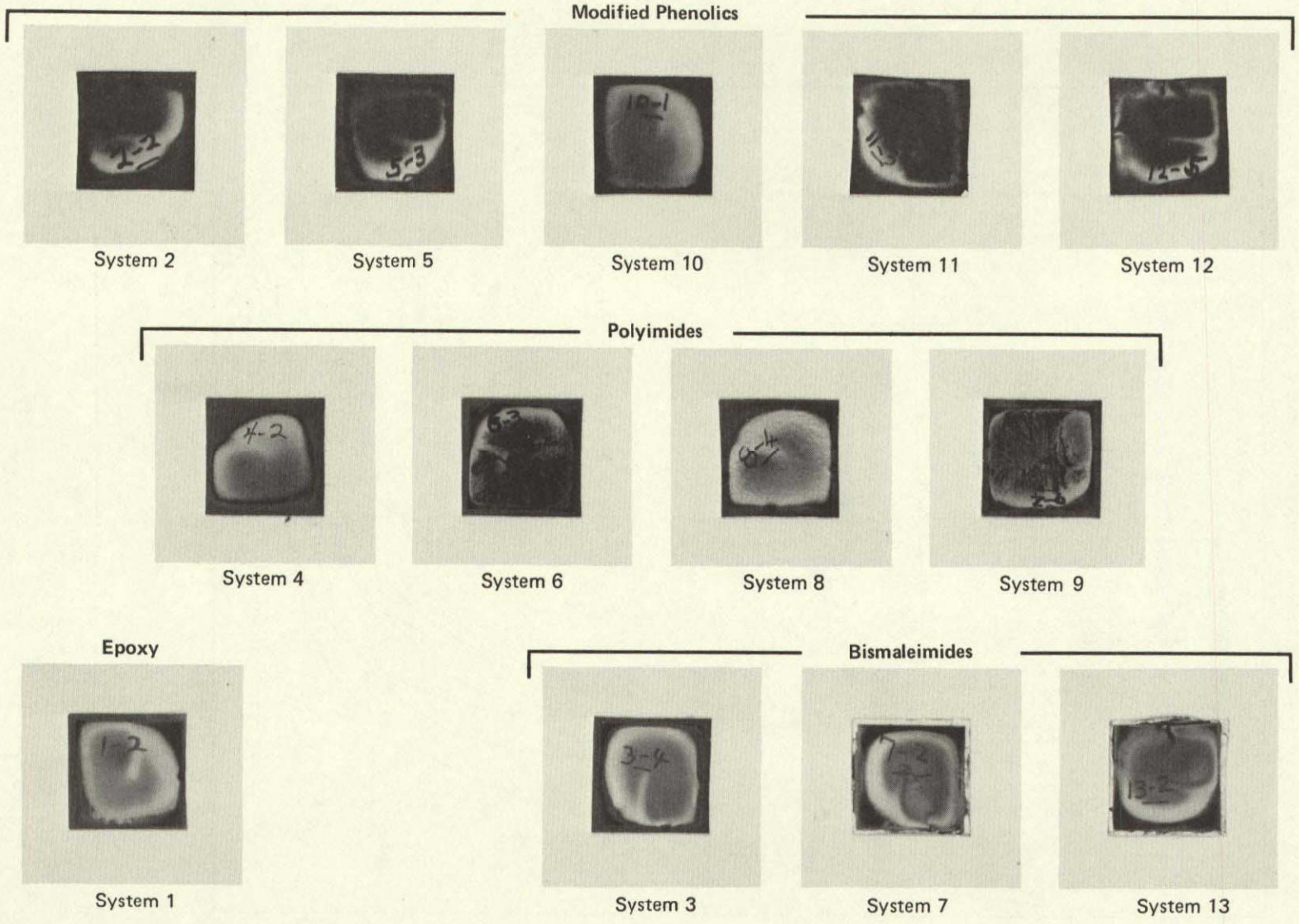


Figure 45.—Boeing Burn Through Test Specimens (Task 2)

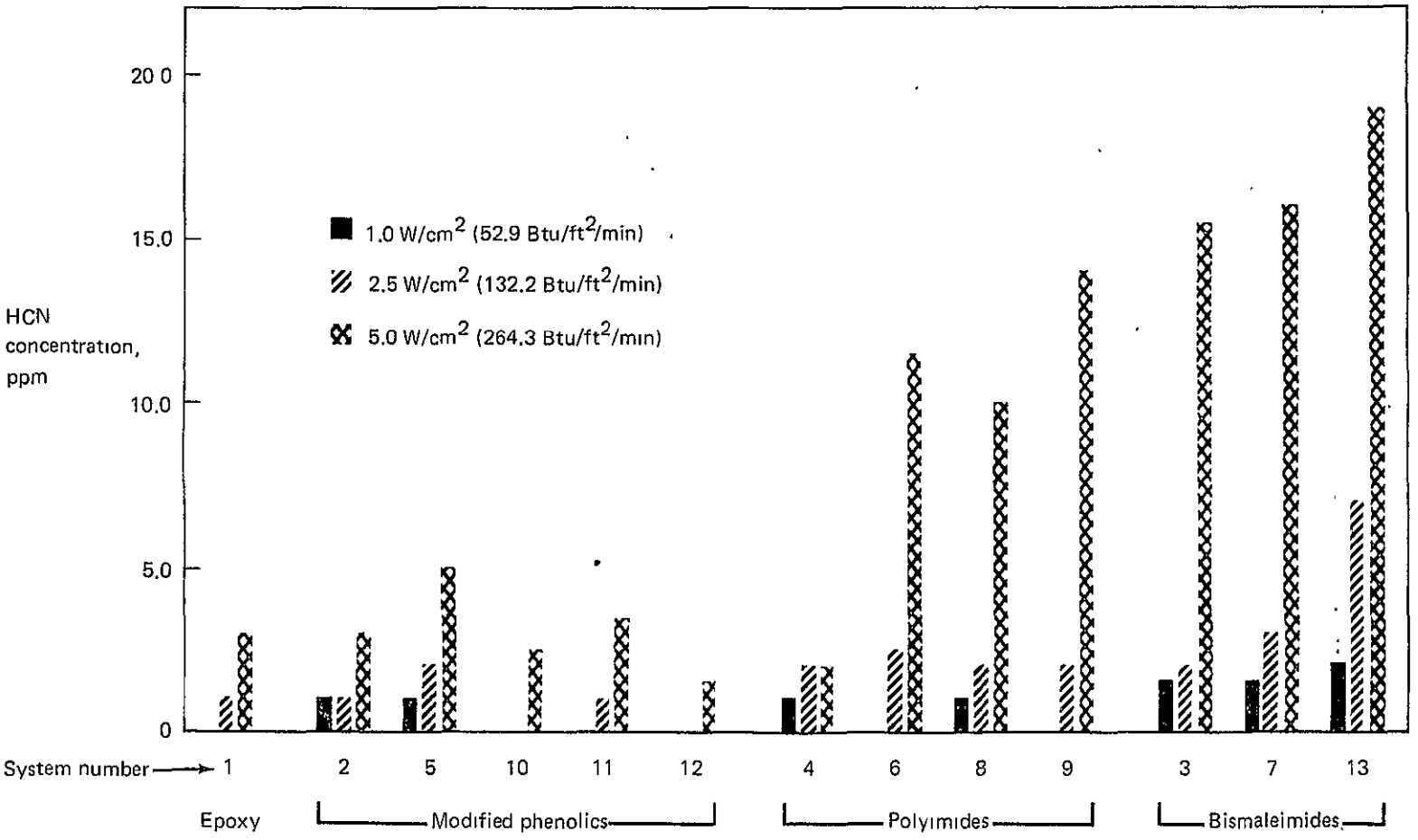


Figure 47.—HCN Evolution as Measured in the NBS Smoke Chamber — 4.0 Minute Sample — Task 2

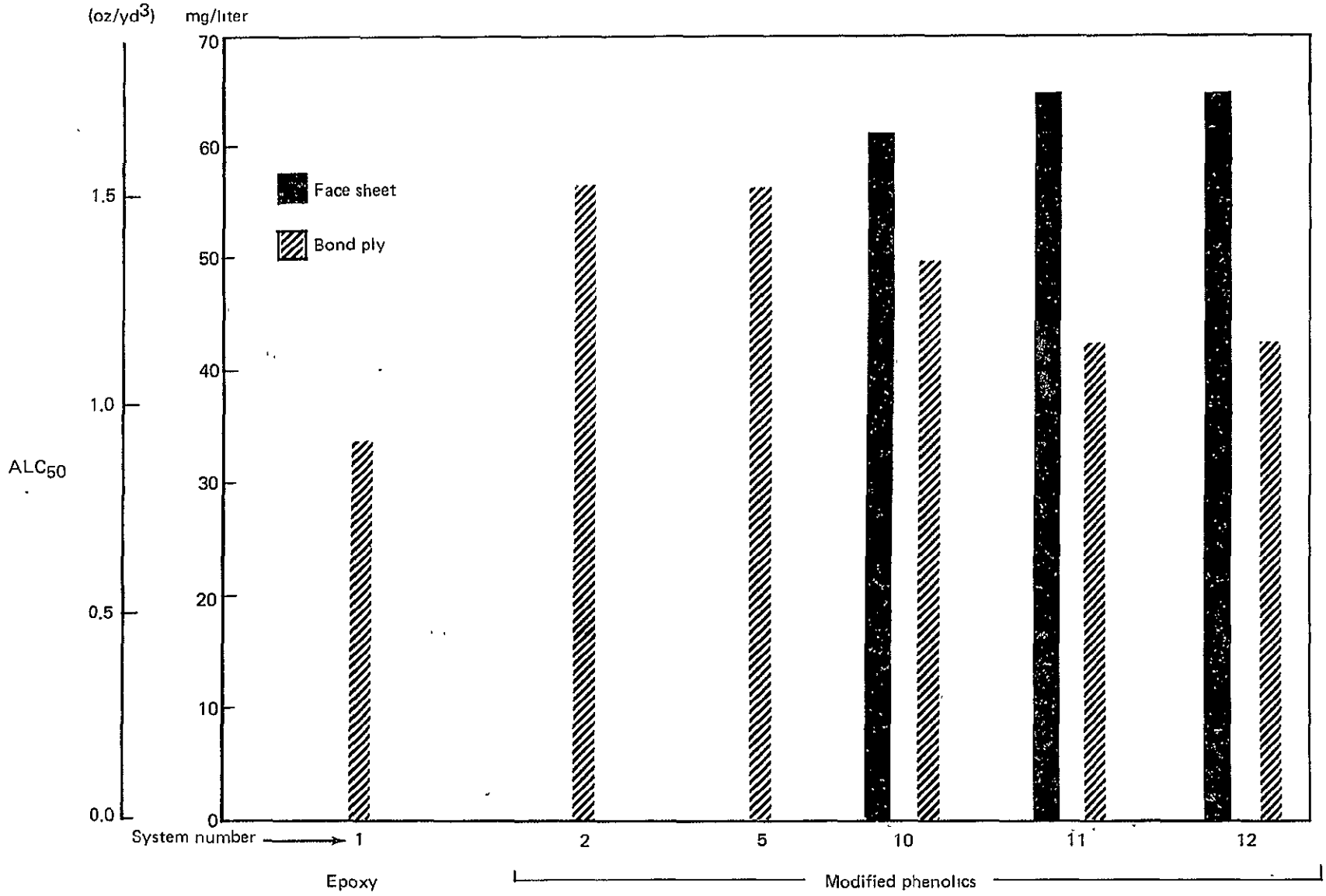


Figure 48.—Apparent Lethal Concentrations of Pyrolysis Products – ALC_{50} – Task 2

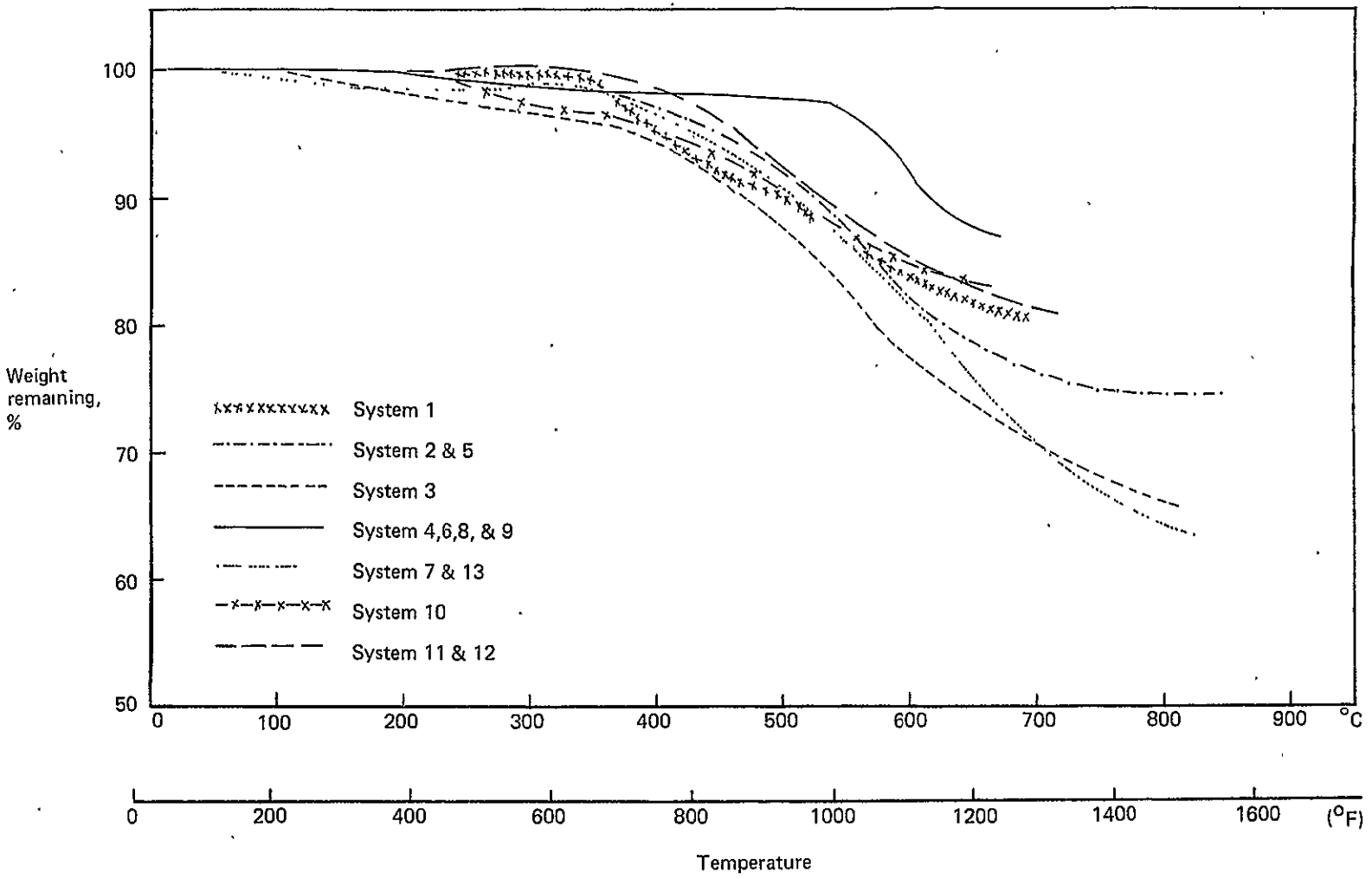


Figure 49.—Thermogravimetric Analysis — Face Sheets — Task 2

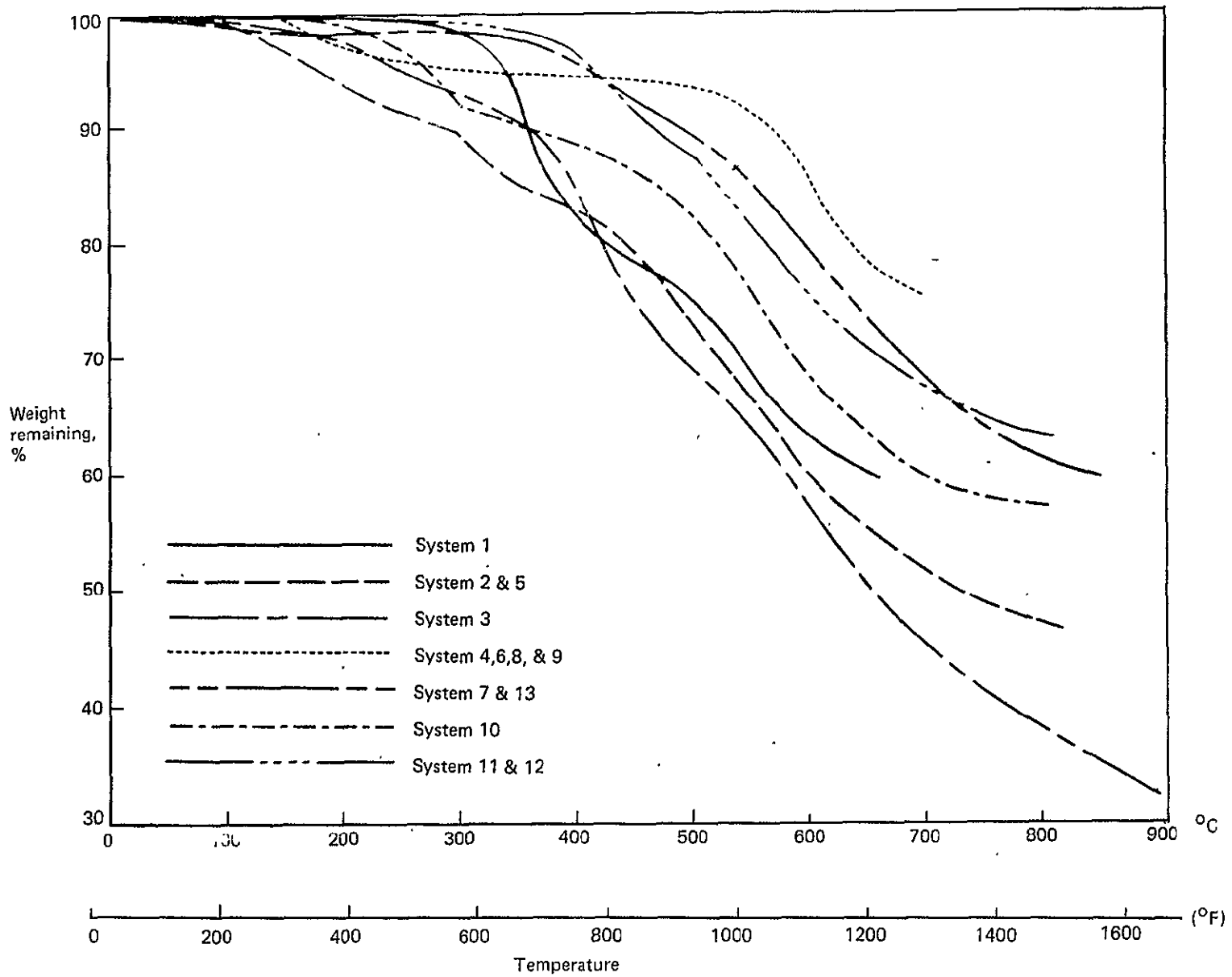


Figure 50.–Thermogravimetric Analysis – Bond Plies – Task 2

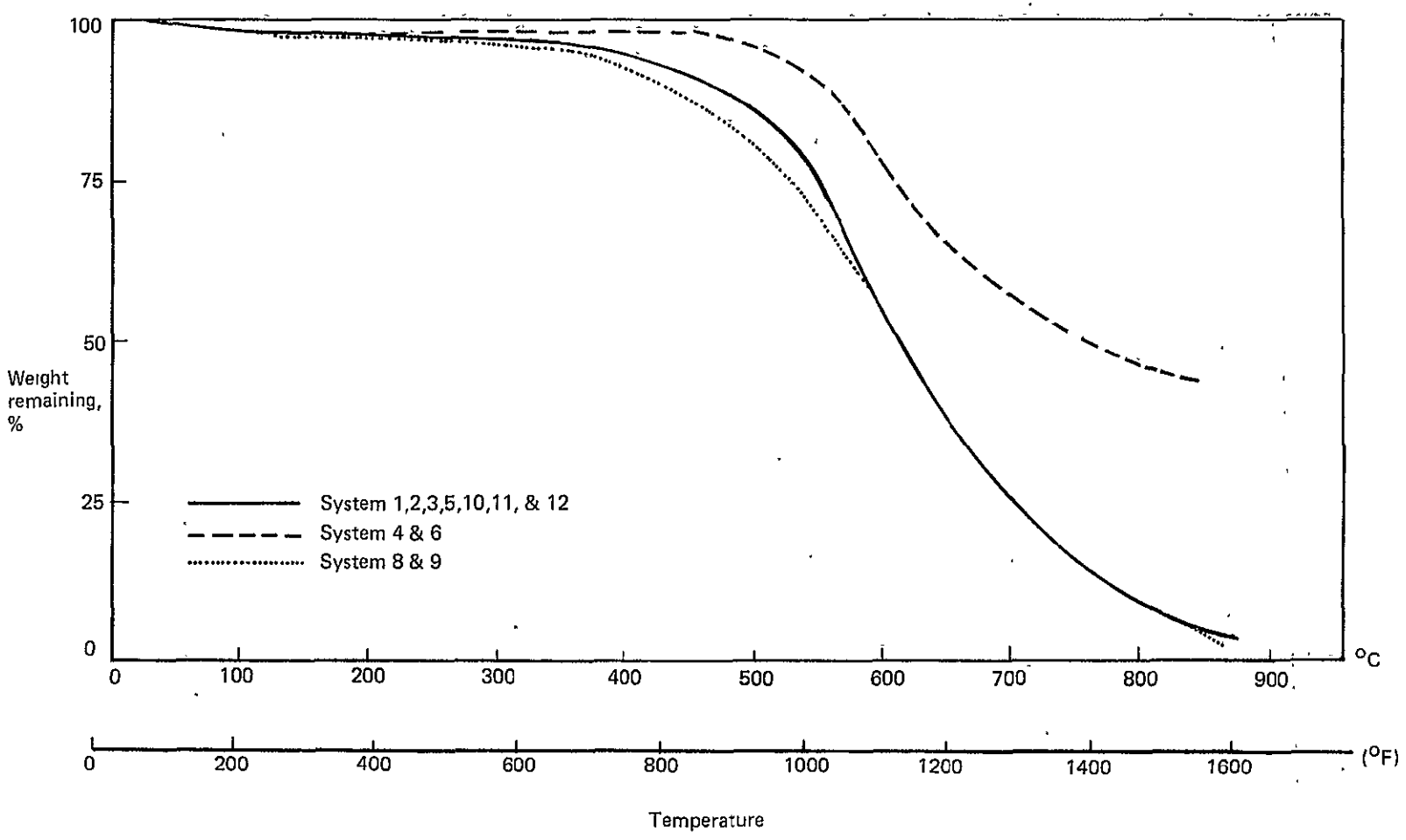


Figure 51.—Thermogravimetric Analysis — Cores — Task 2

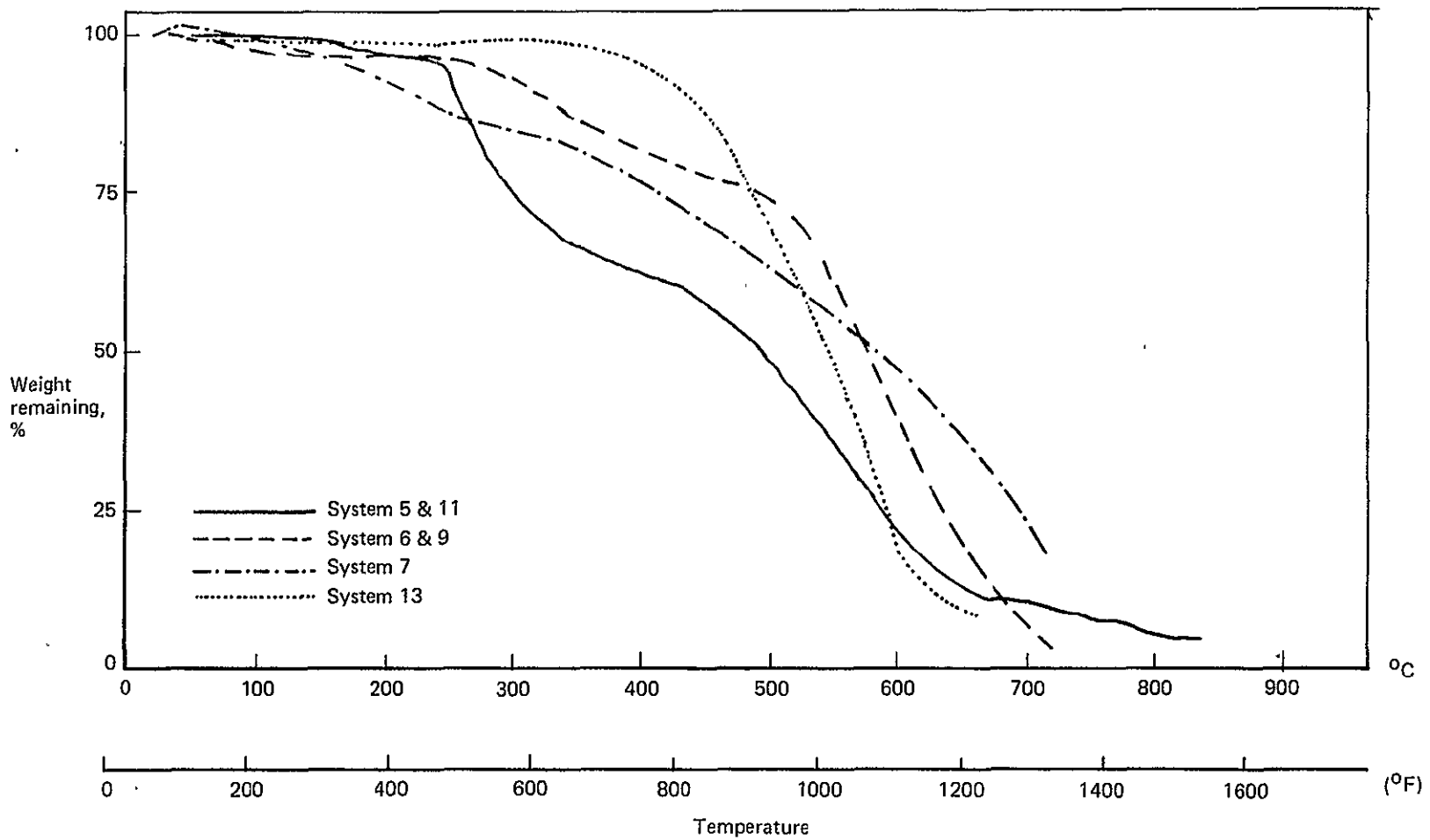


Figure 52.—Thermogravimetric Analysis — Foams — Task 2

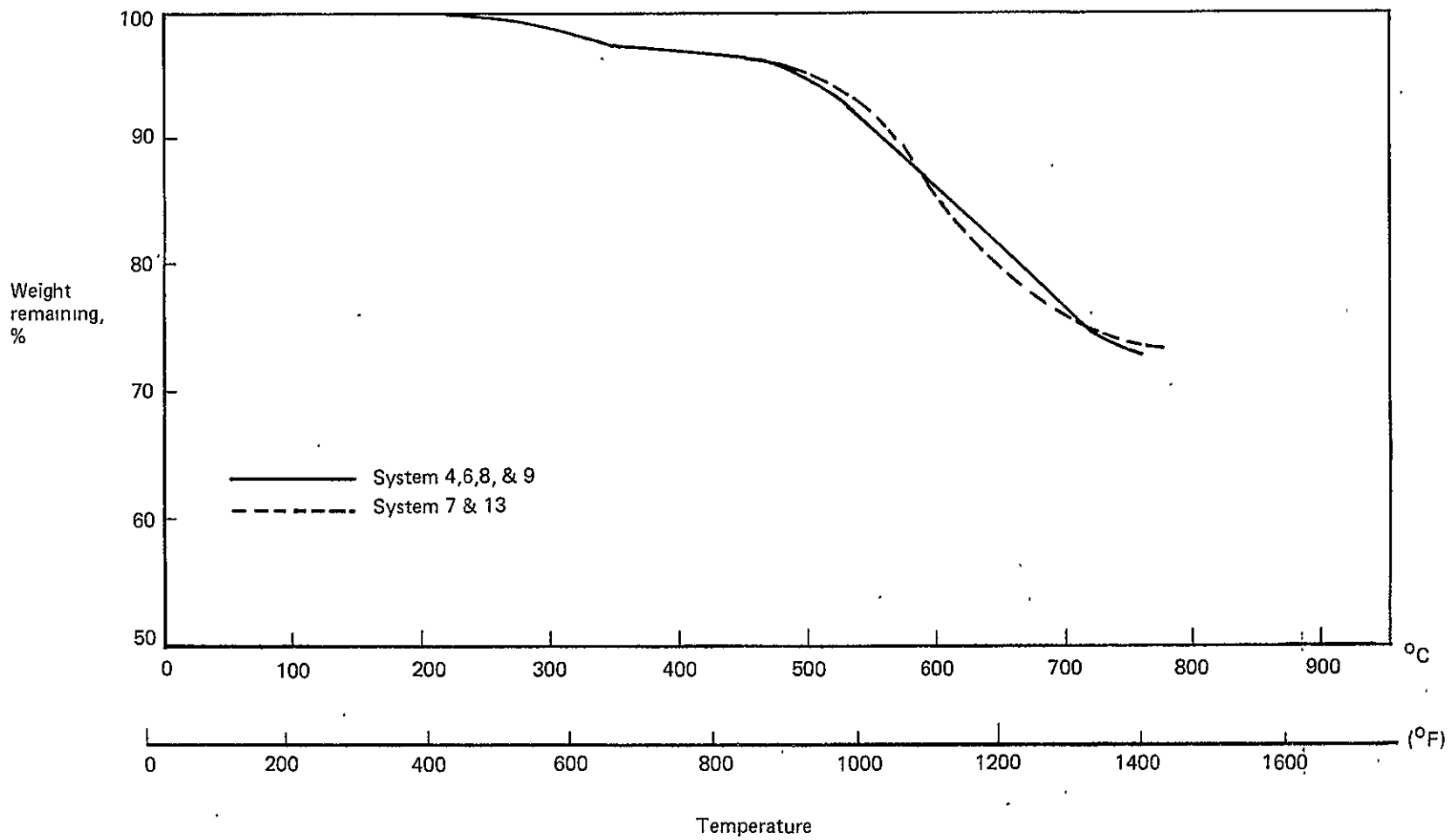


Figure 53.—Thermogravimetric Analysis — Adhesives — Task 2

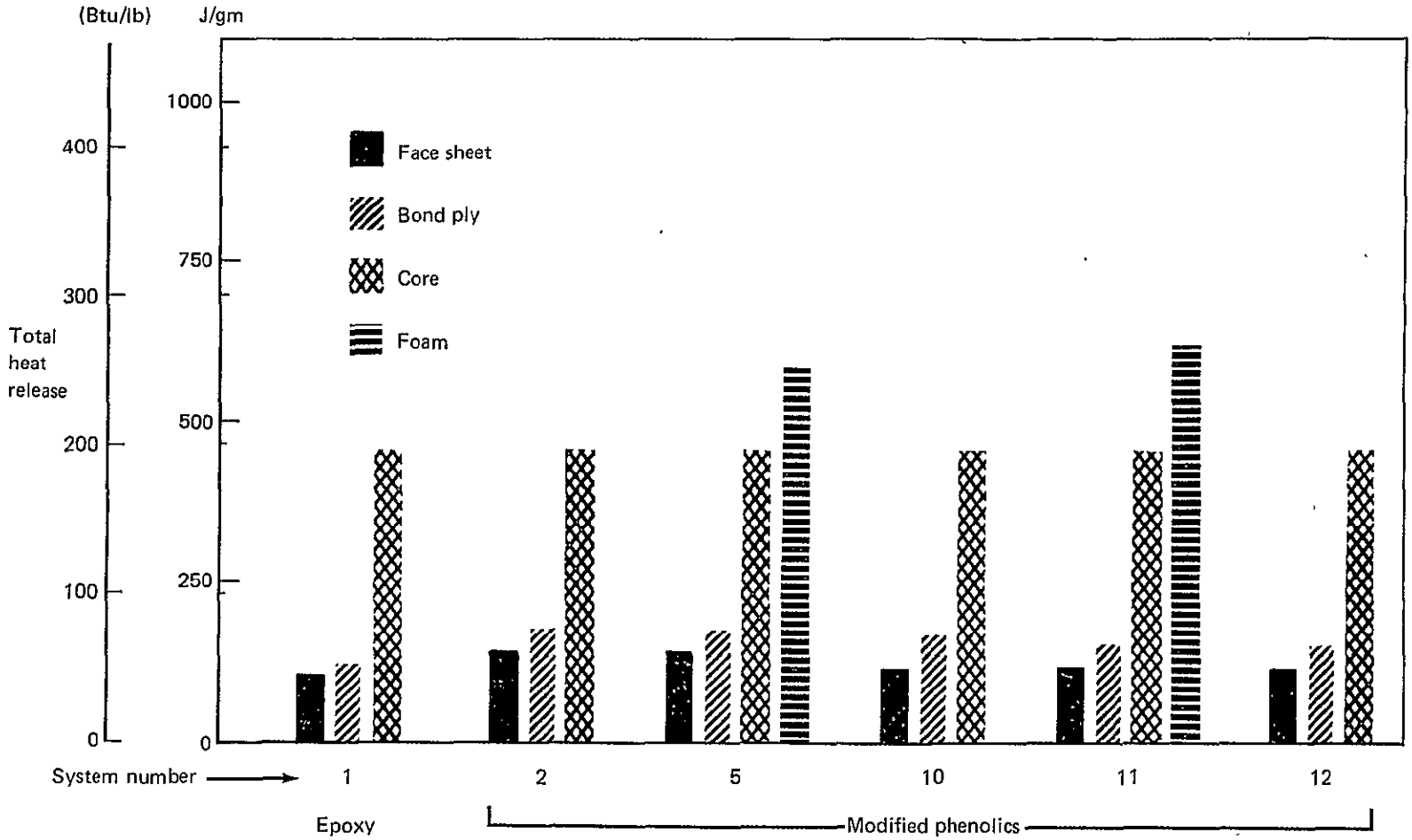


Figure 54.—Total Heat Released — DTA — Phenolics — Task 2

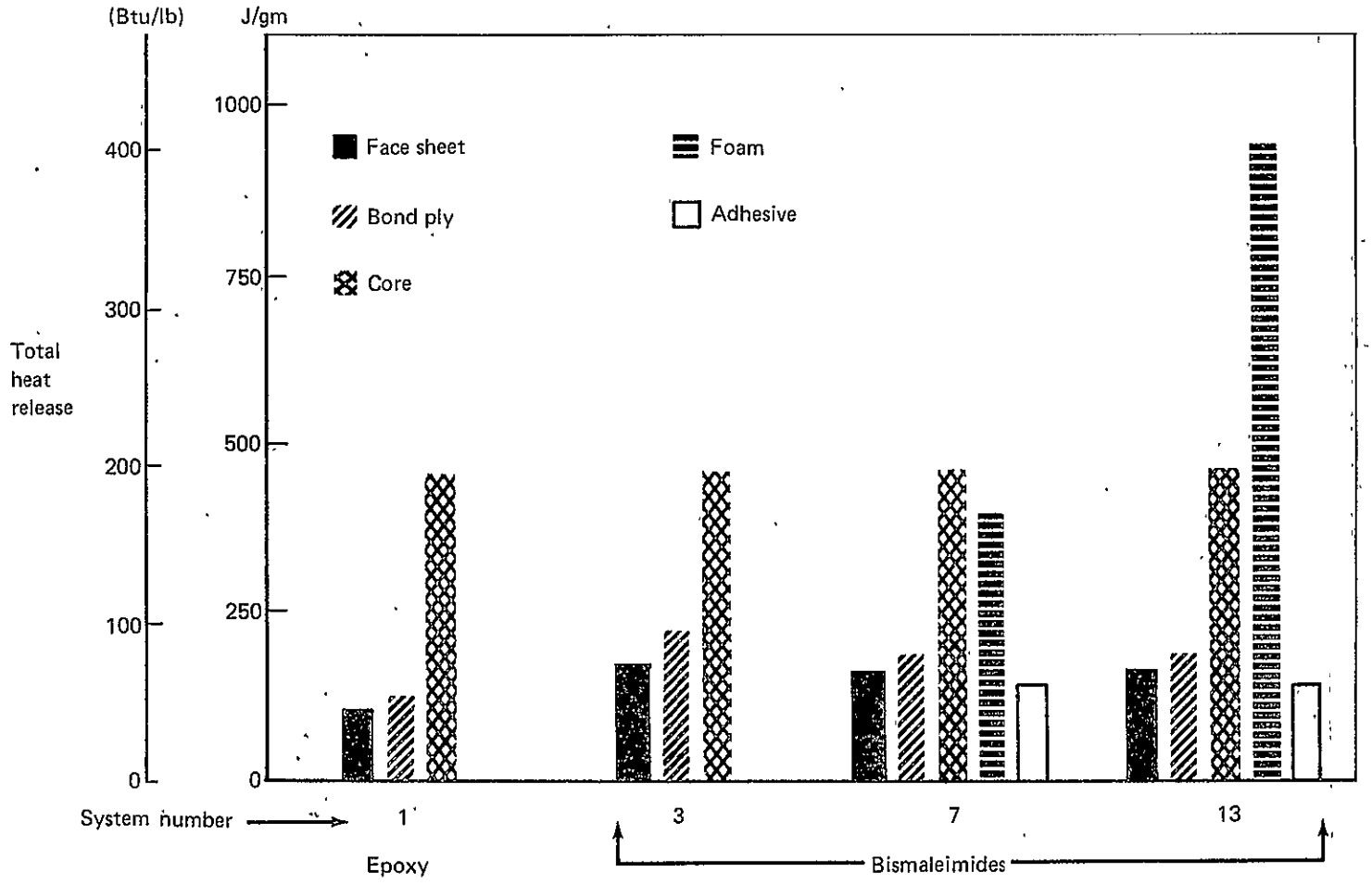


Figure 55.—Total Heat Released — DTA — Bismaleimides — Task 2

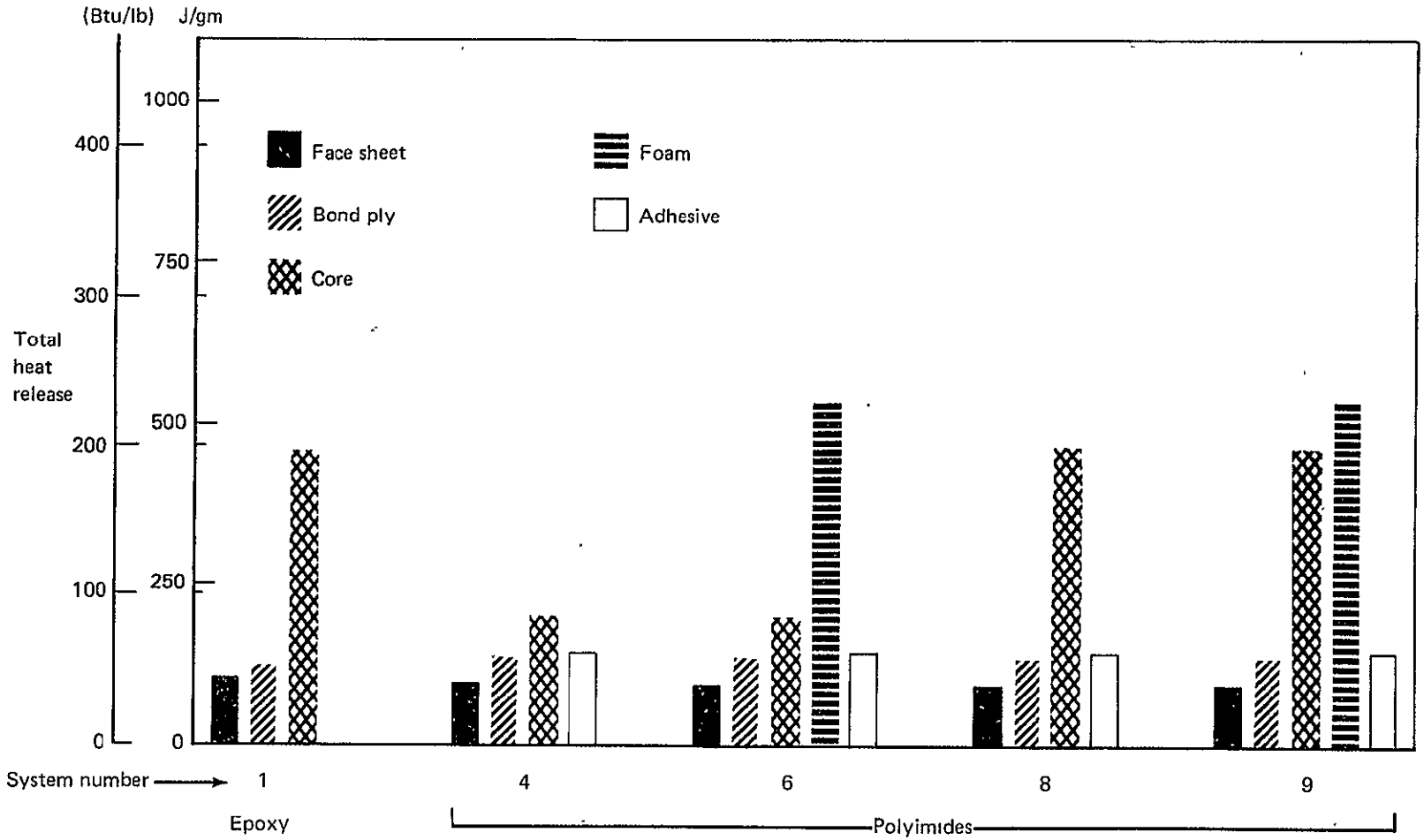


Figure 56.—Total Heat Released — DTA — Polyimides — Task 2

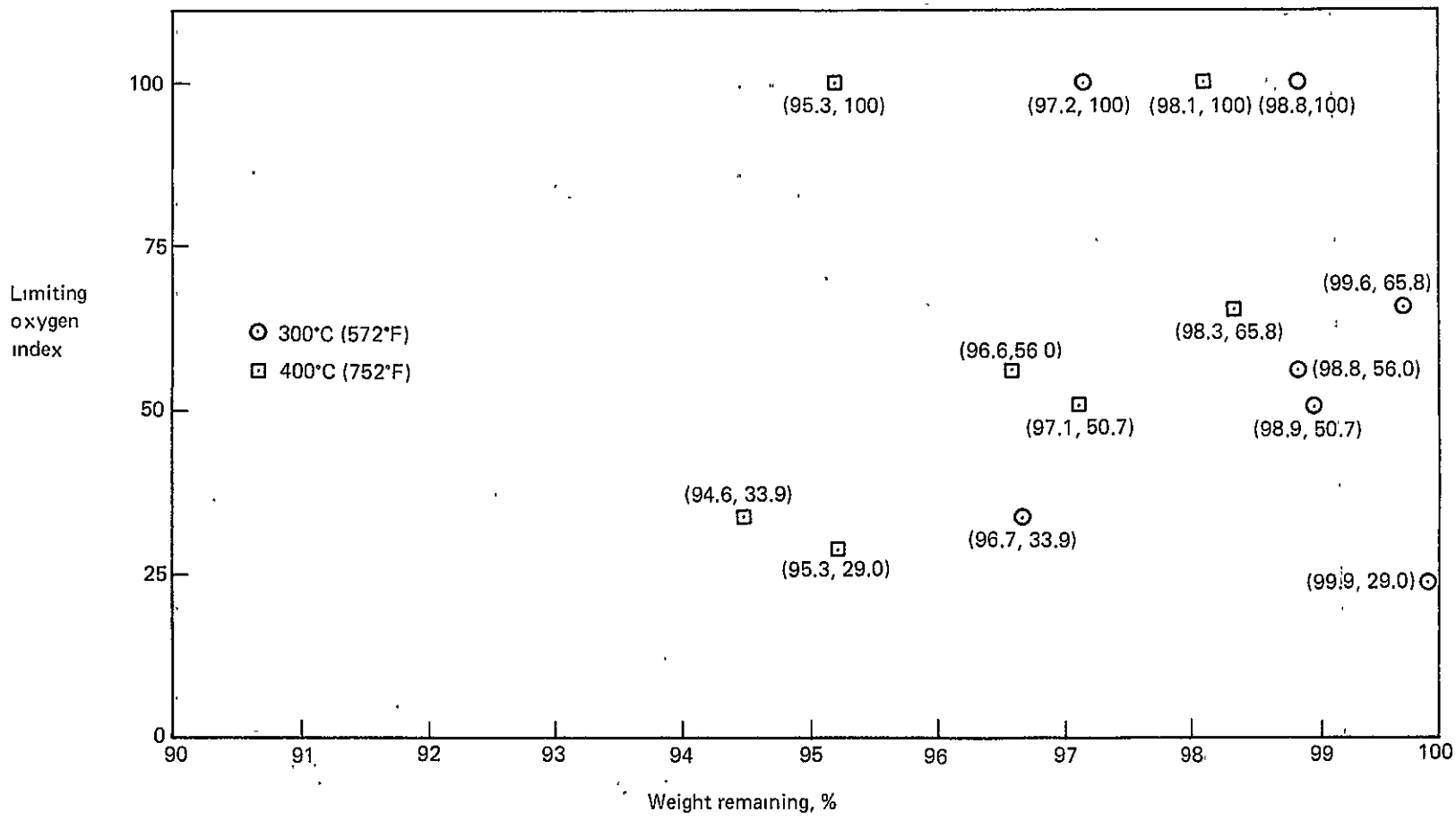


Figure 57.—Limiting Oxygen Index Versus Thermogravimetric Weight Loss — Facesheets — Task 2

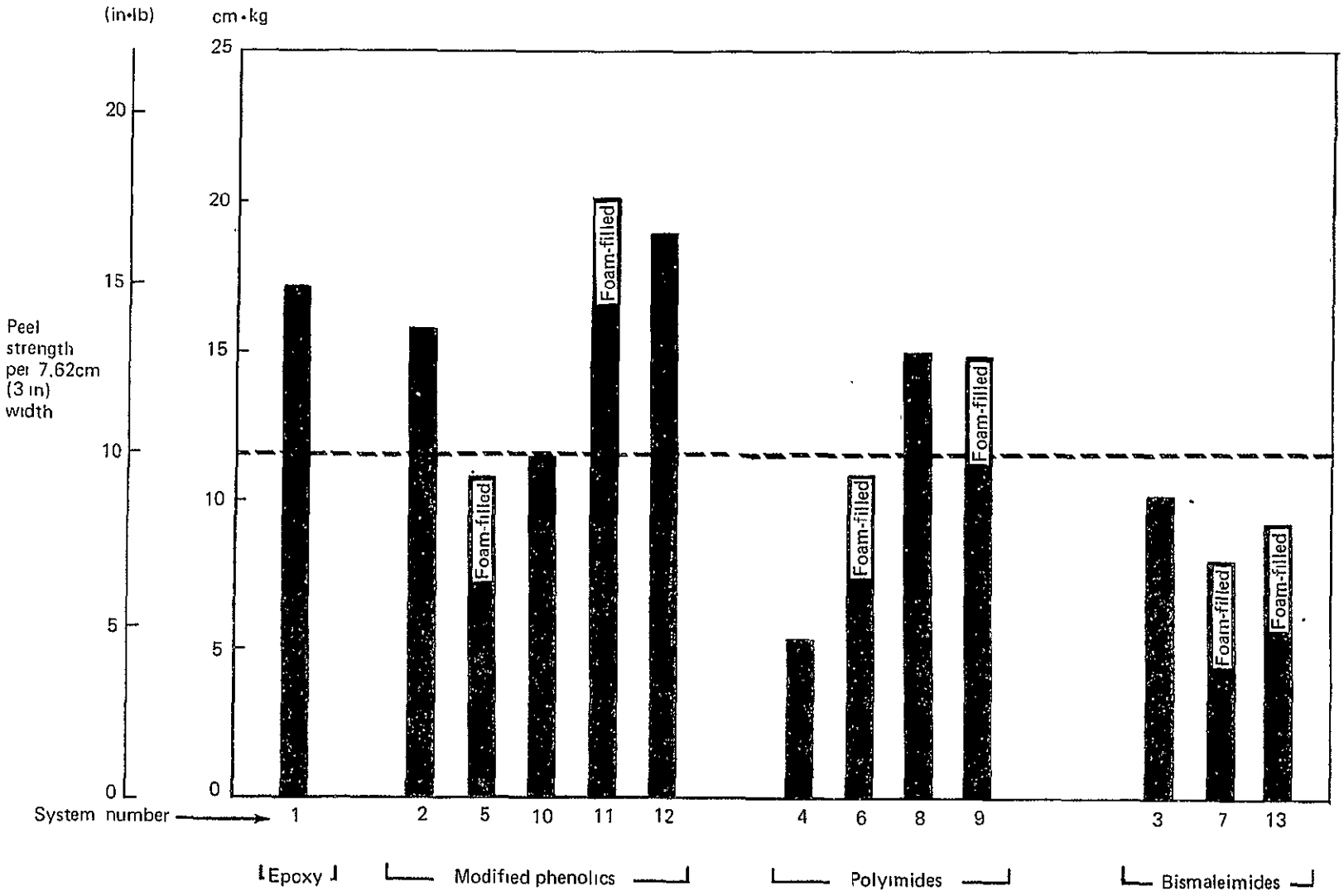


Figure 59.---Peel Strength — Task 2

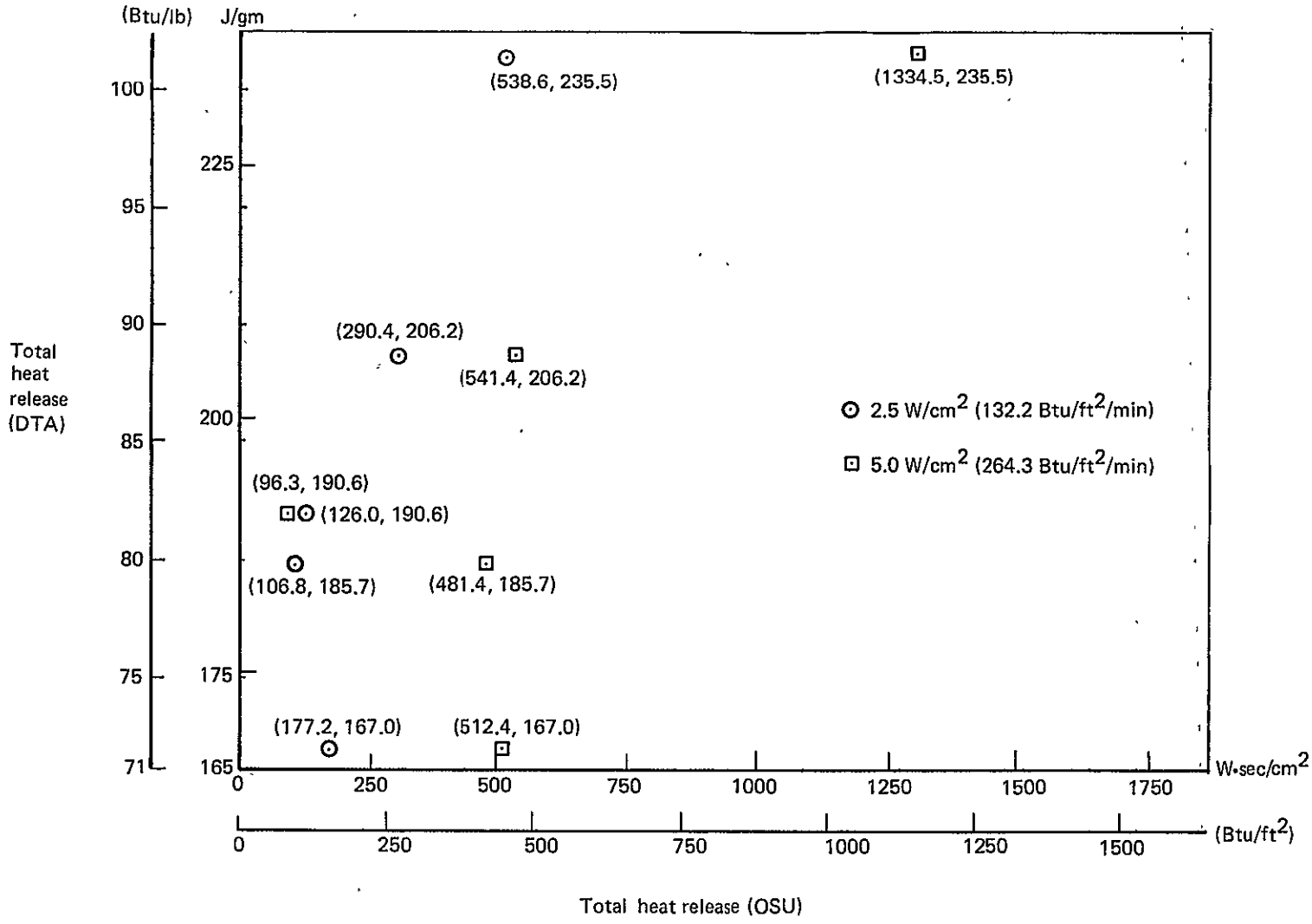


Figure 58.–DTA Versus OSU Heat Release – Task 2

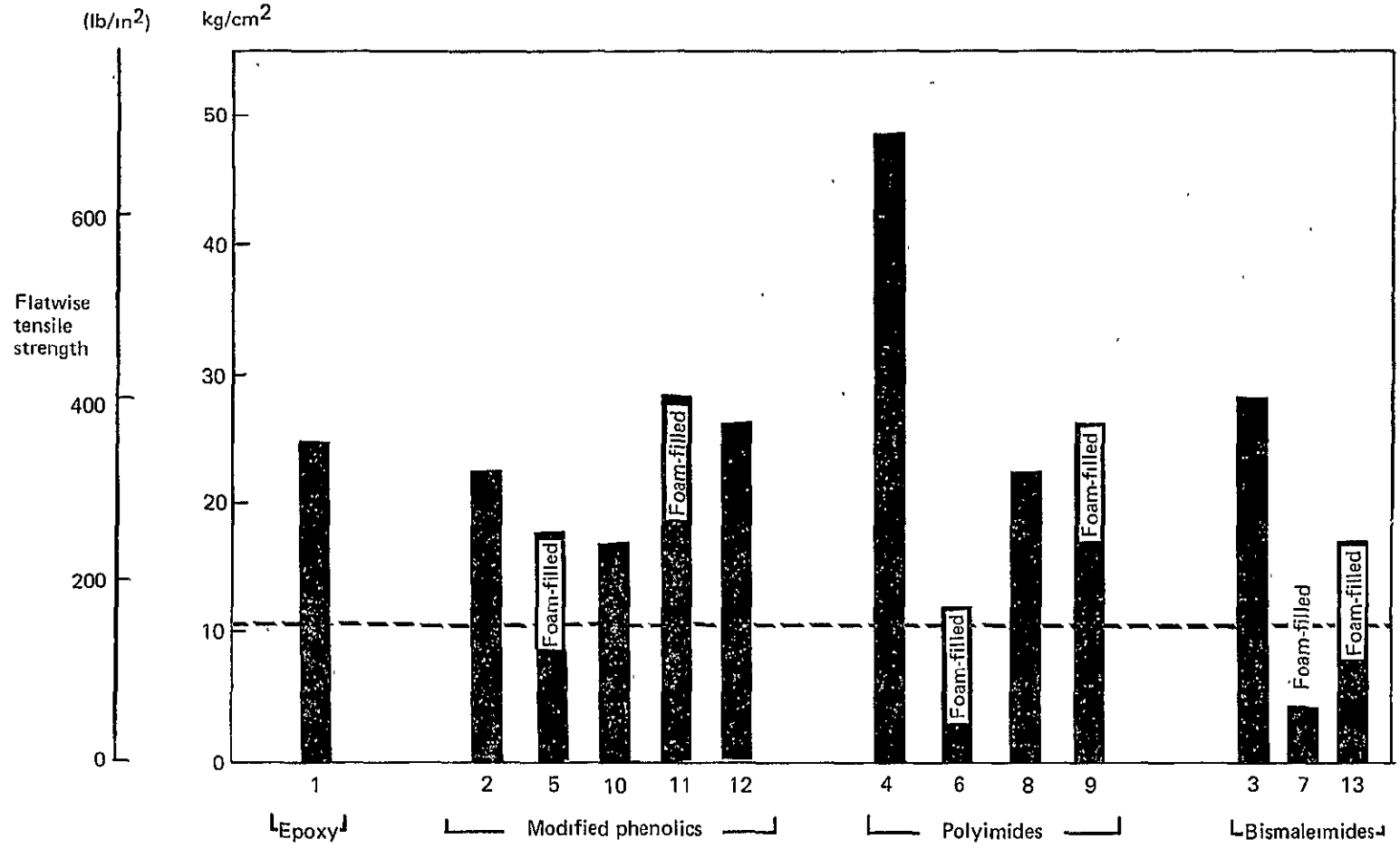


Figure 60.—Flatwise Tensile Strength — Task 2

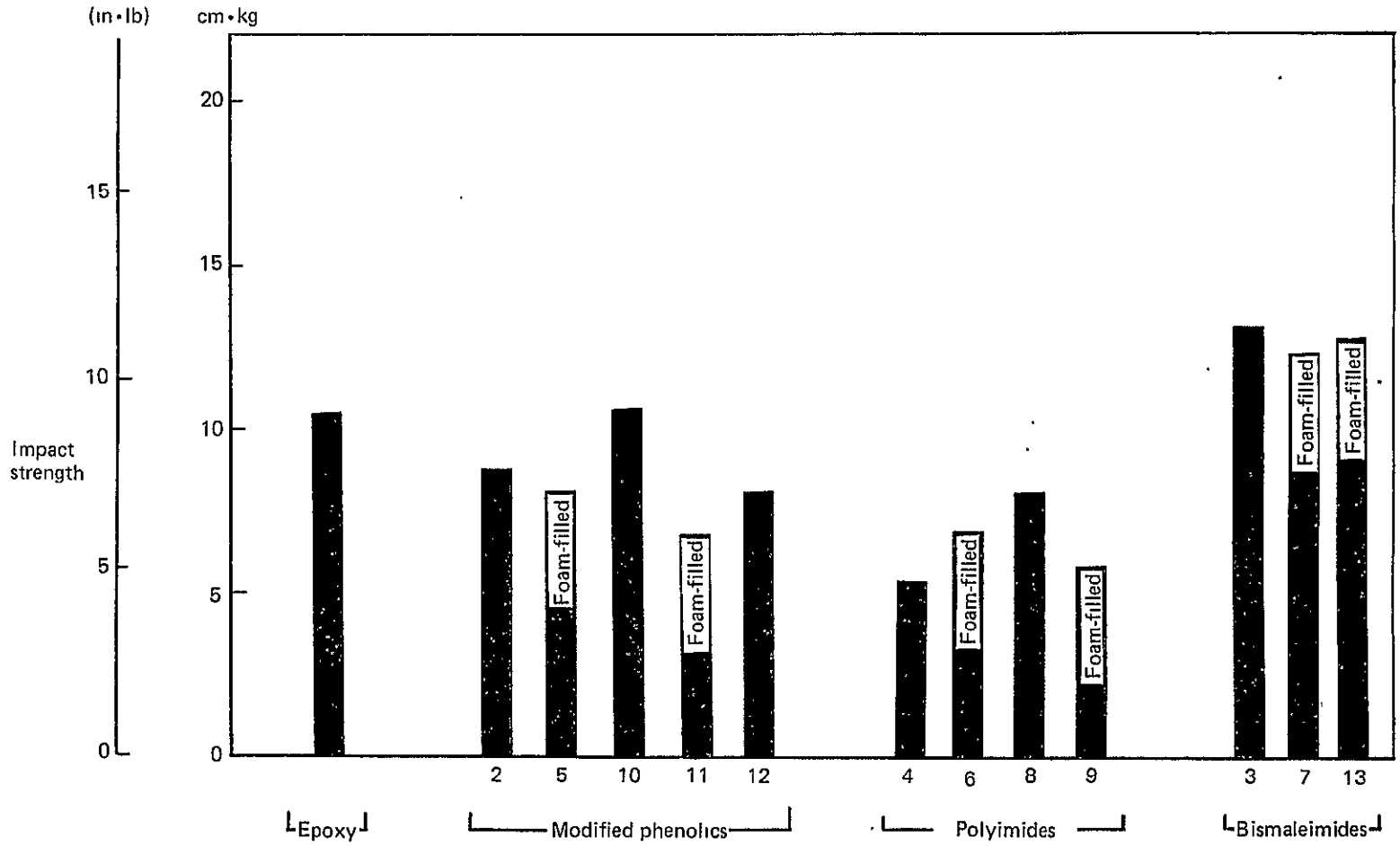


Figure 61.—Gardener Impact Strength — Task 2

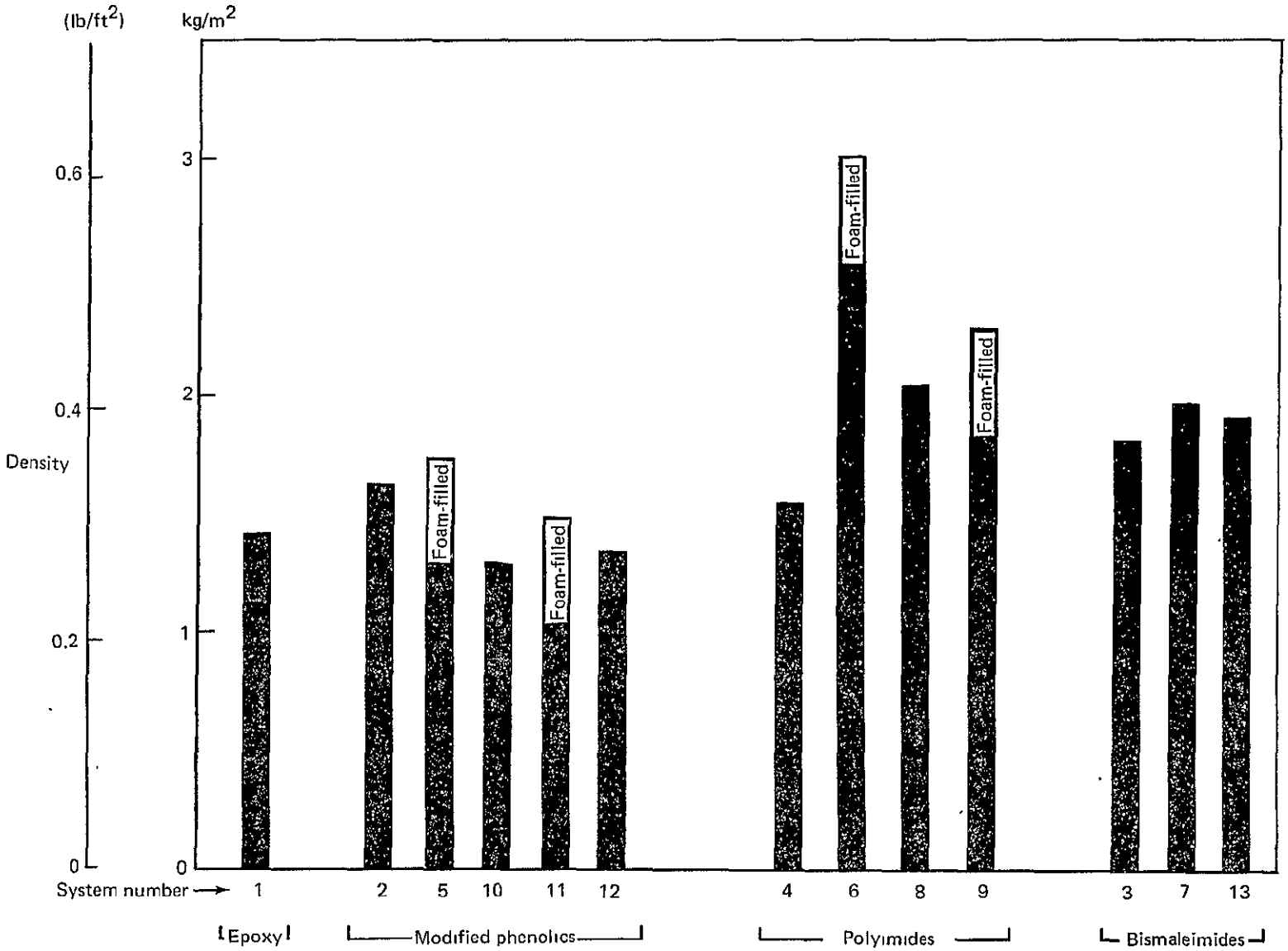


Figure 62.—Density — Task 2

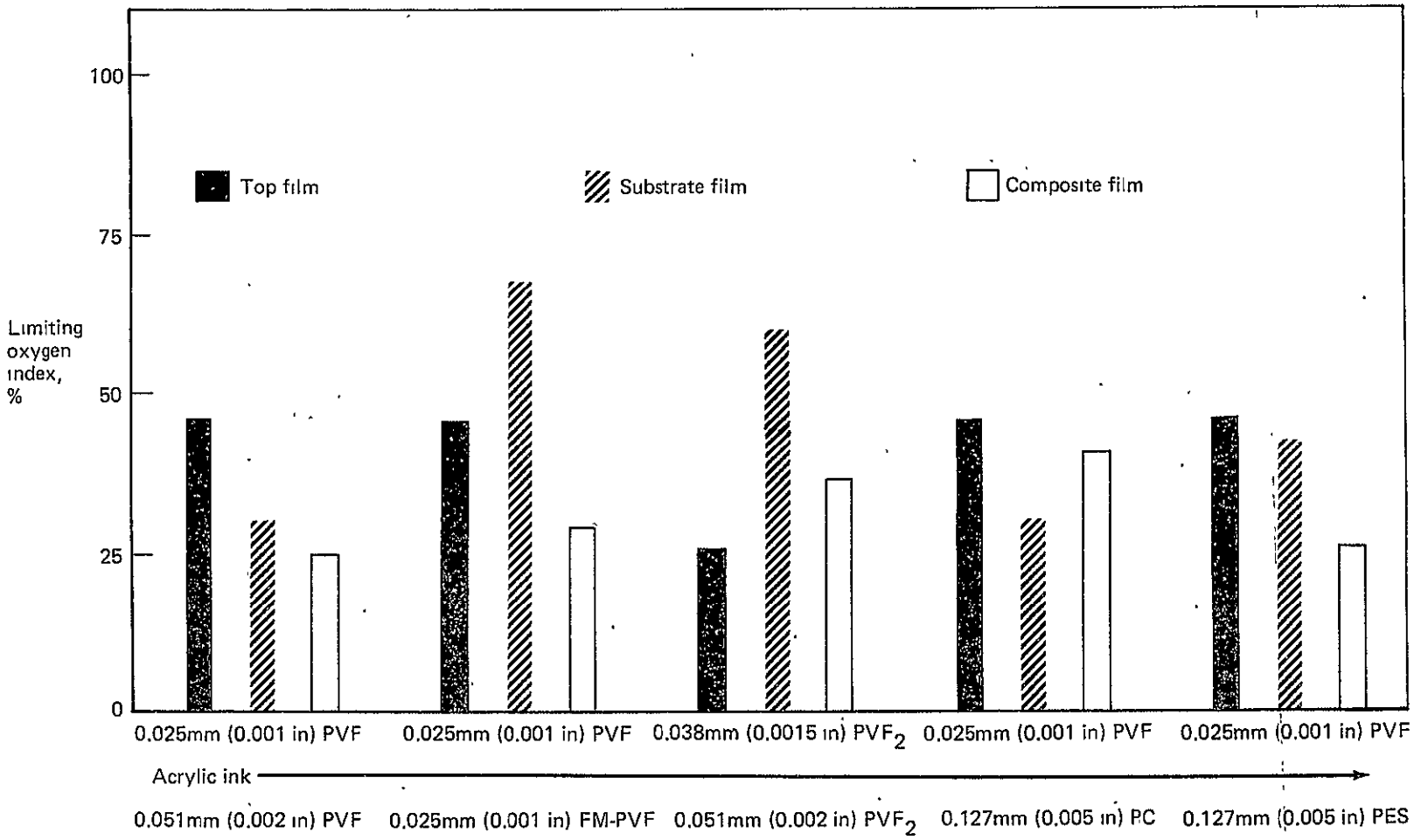


Figure 63.—Limiting Oxygen Index — Decorative Films — Task 3

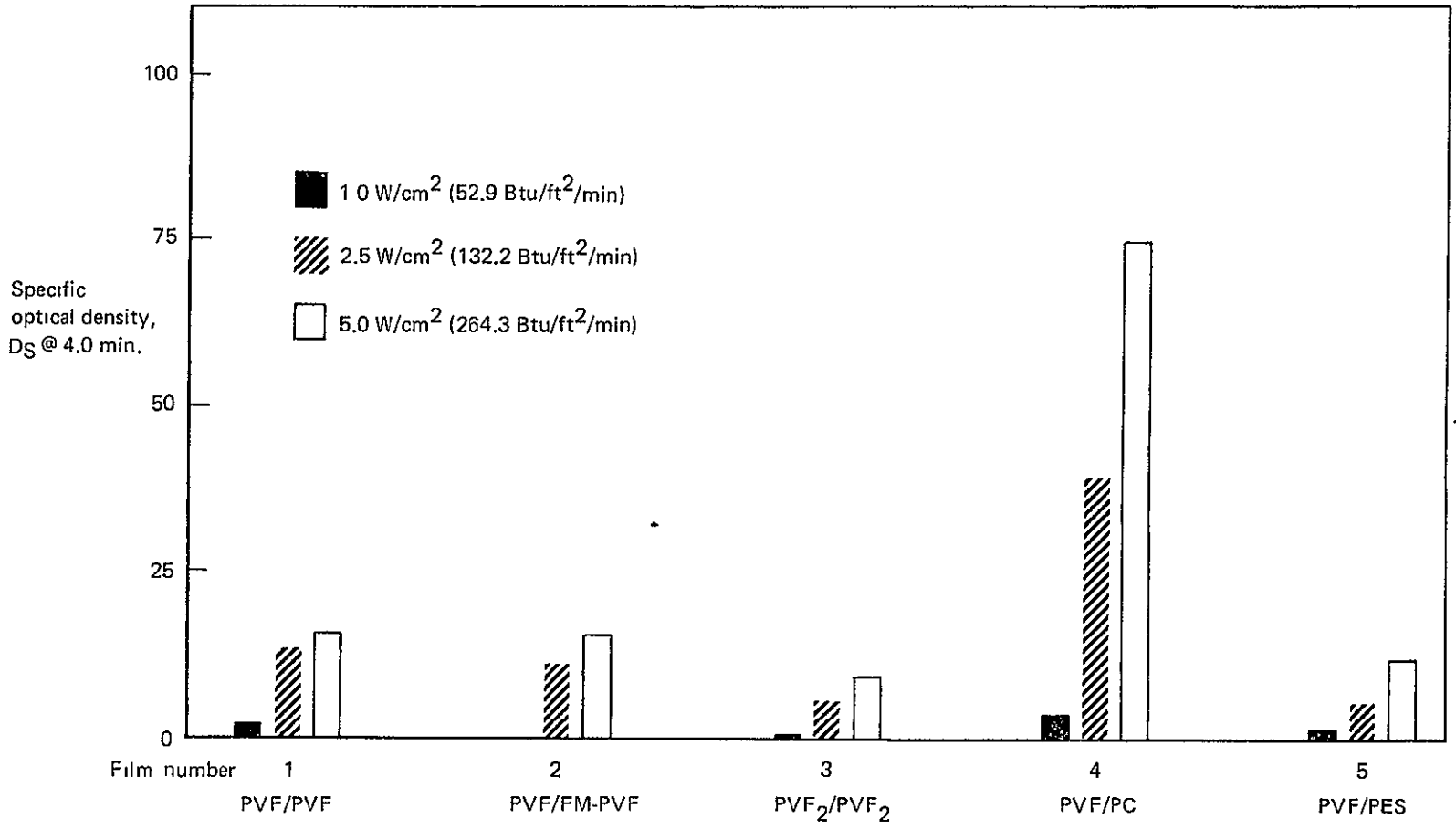


Figure 64.–Smoke Emission as Measured in the NBS Smoke Chamber – D_S – Task 3

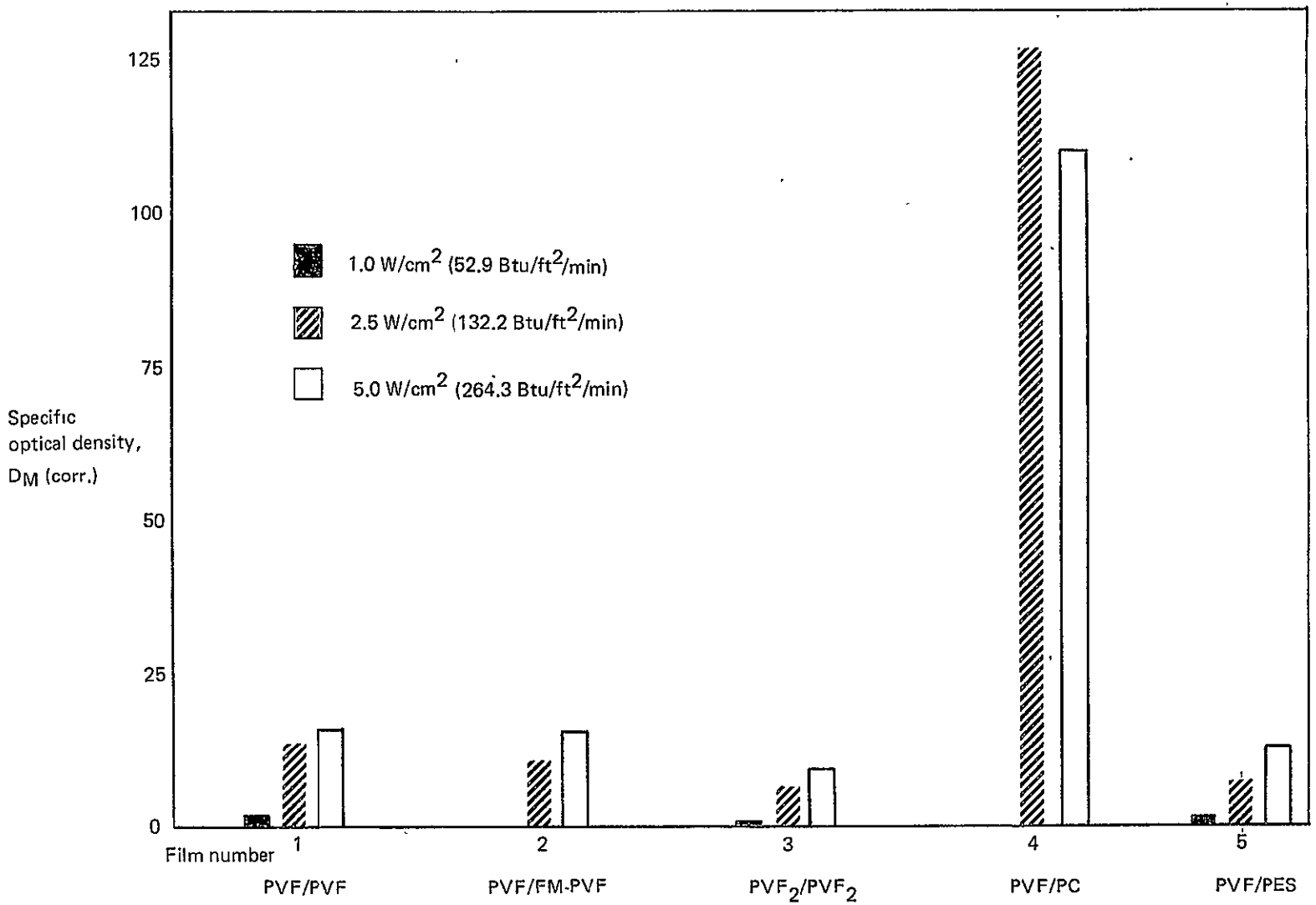


Figure 65.—Smoke Emission as Measured in the NBS Smoke Chamber — D_M— Task 3

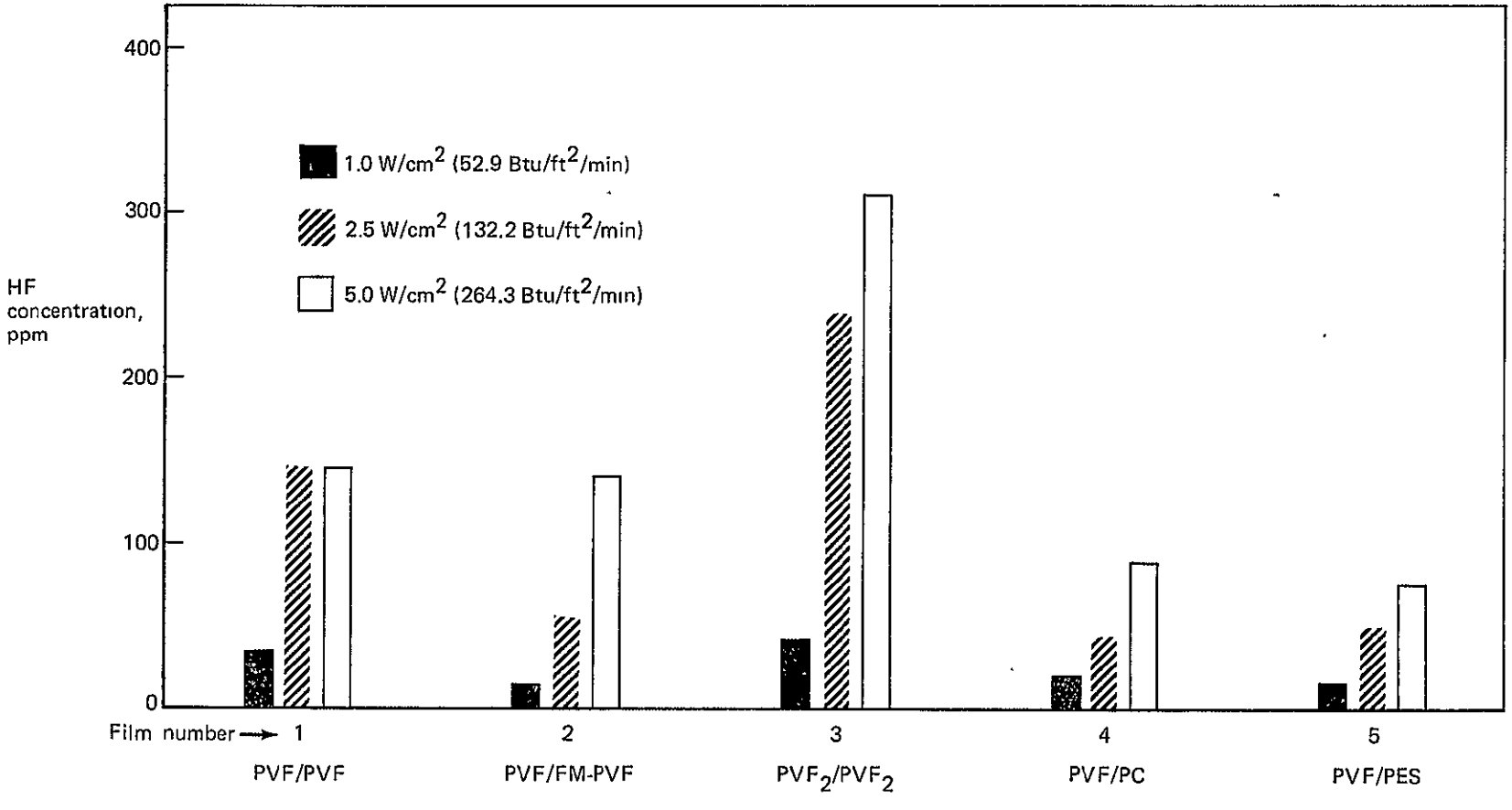


Figure 66.—HF Evolution as Measured in the NBS Smoke Chamber — 4.0 Minute Sample — Task 3

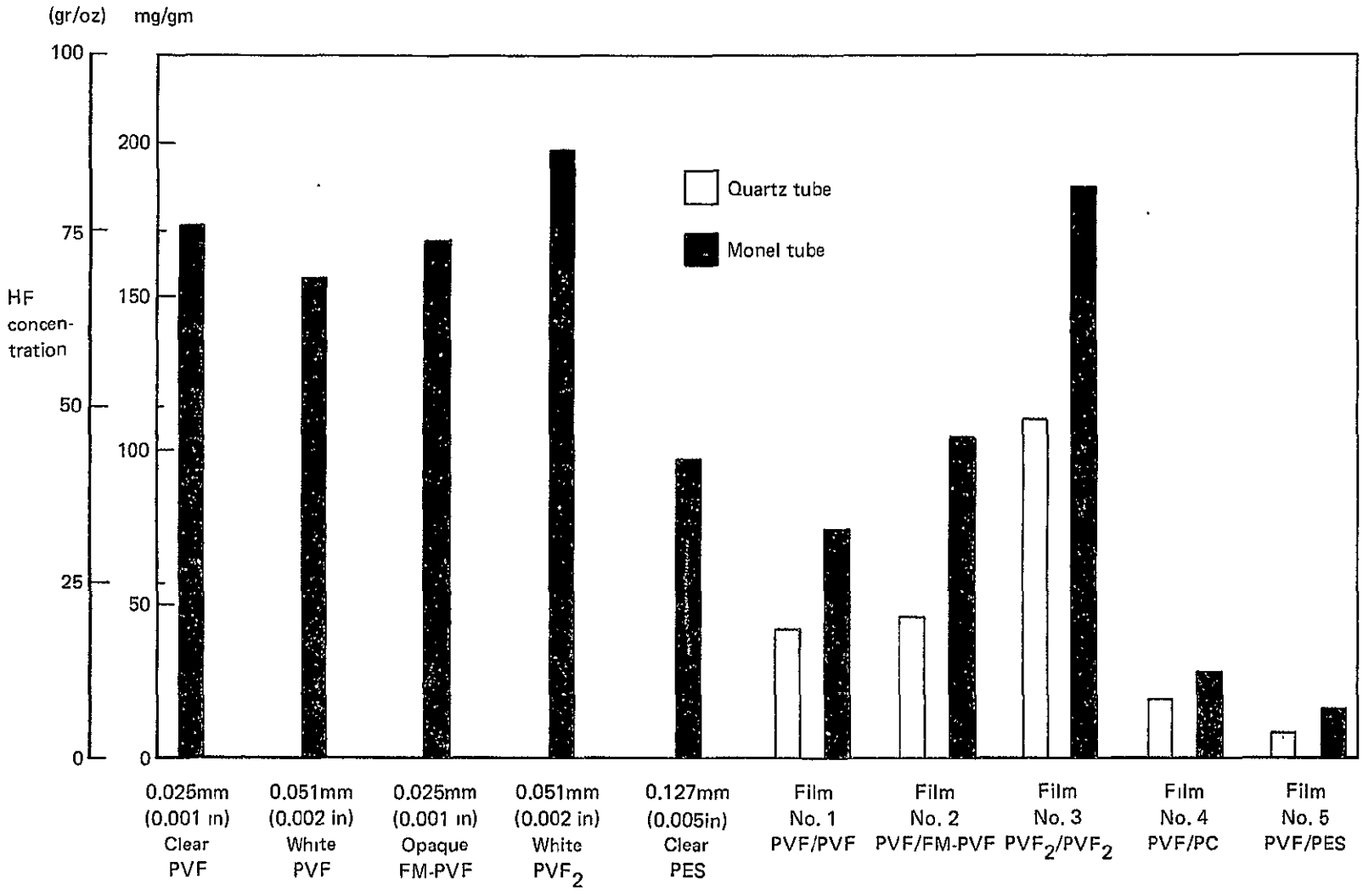


Figure 67.—Pyrolysis Tube Decomposition — Task 3

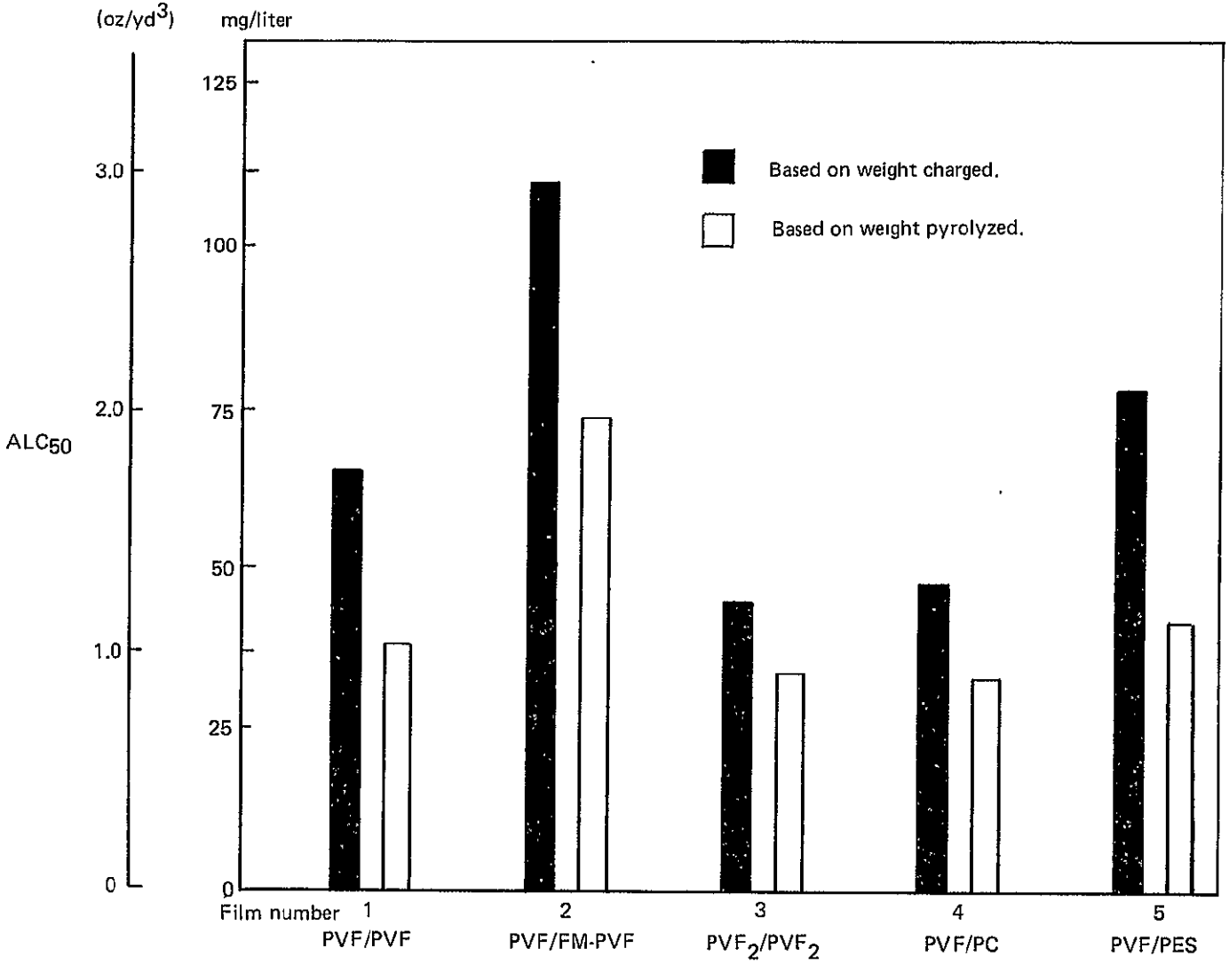


Figure 68.—Apparent Lethal Concentration of Pyrolysis Products — ALC_{50} — Task 3

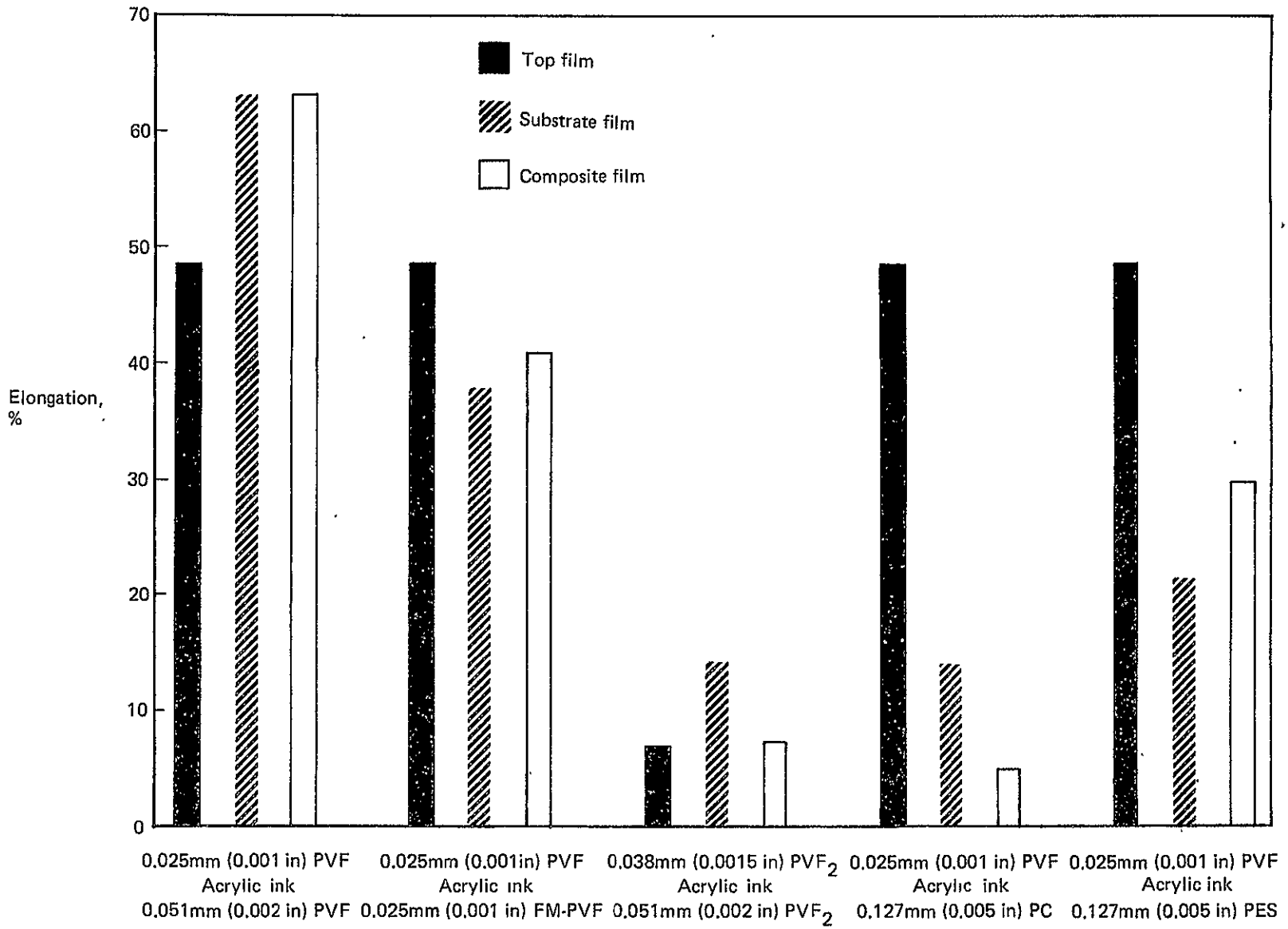


Figure 69.—Decorative Film Elongation — Task 3

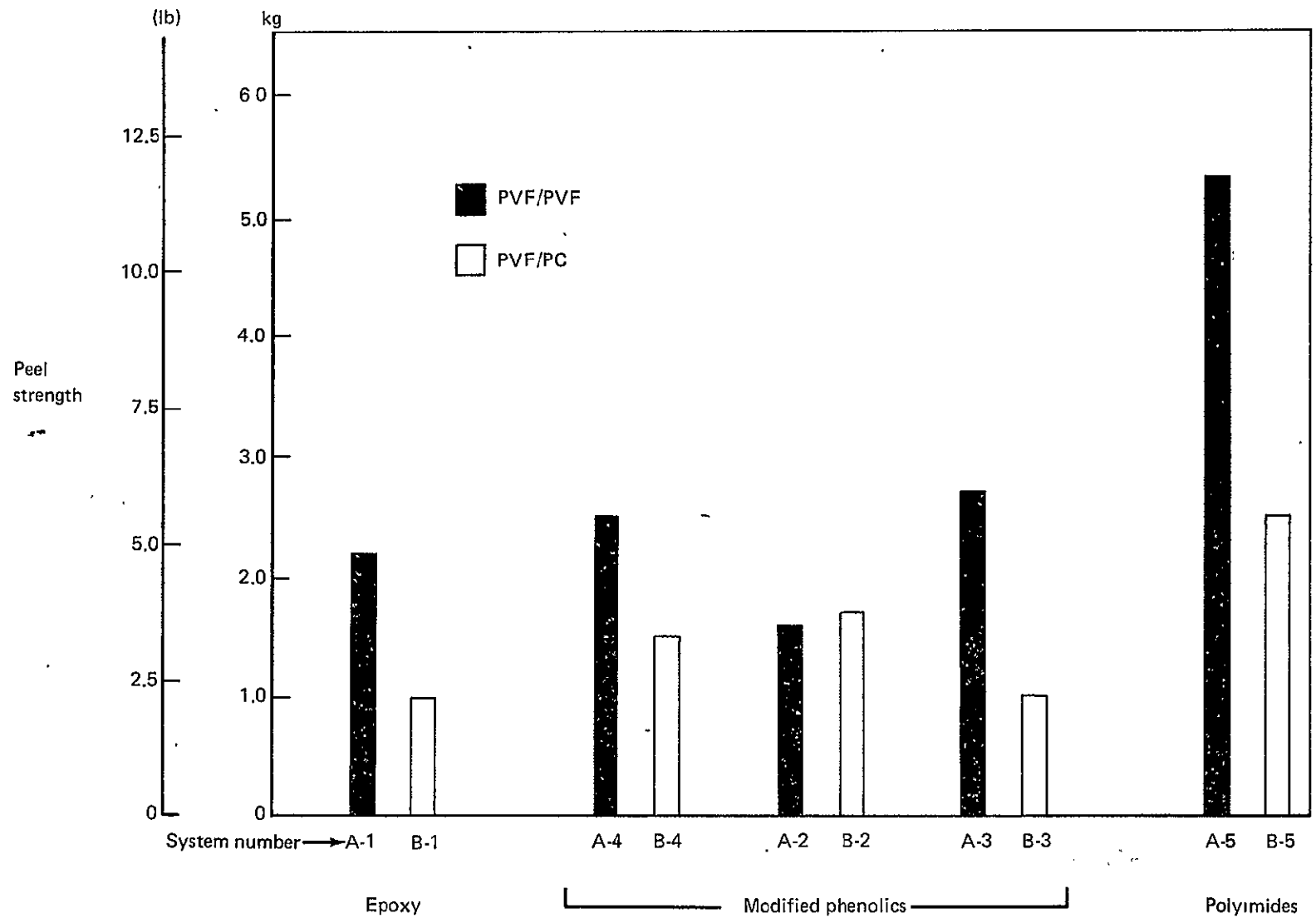


Figure 70.—Decorative Film Peel Strength — Task 4

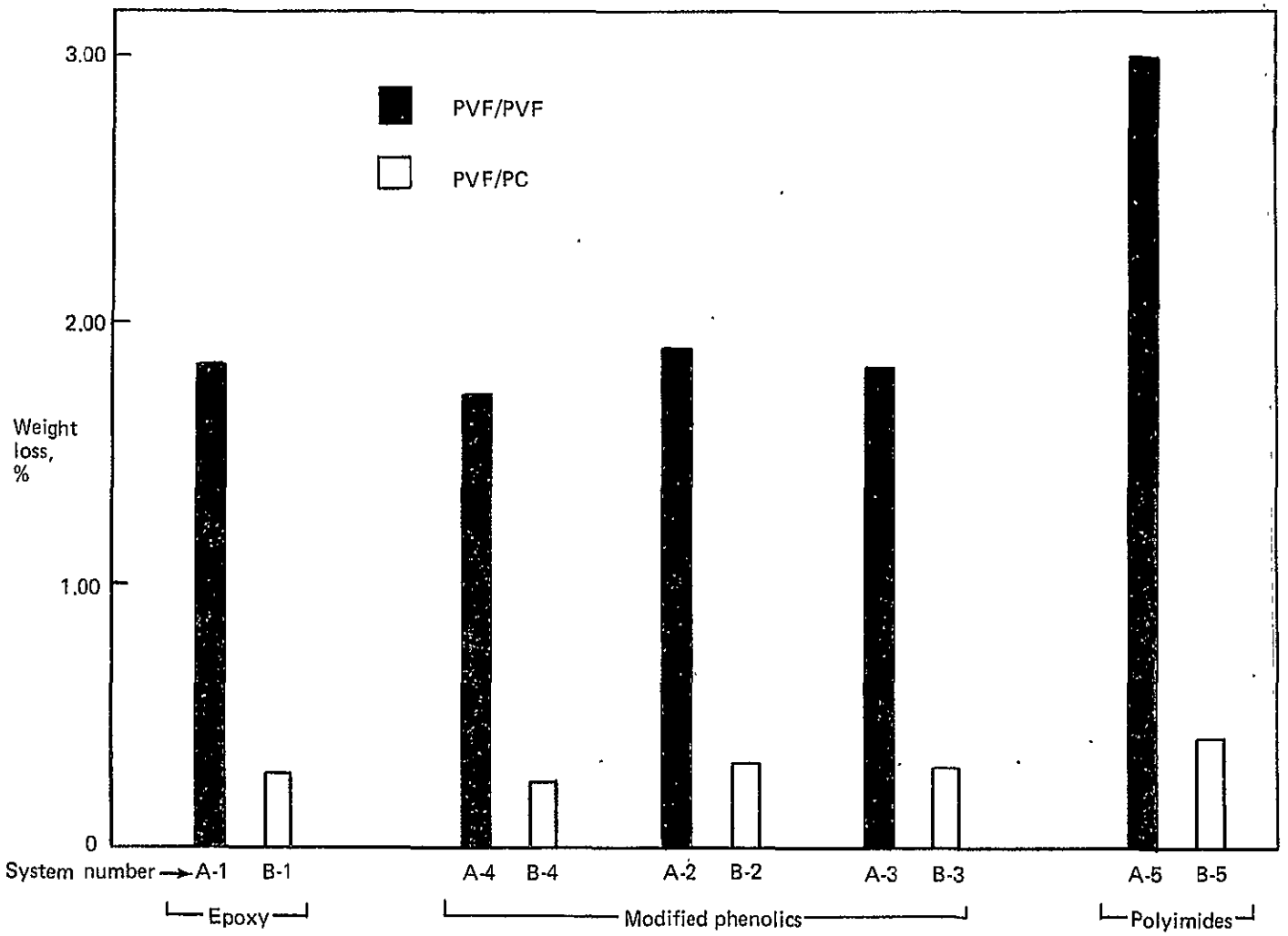


Figure 71.—Decorative Film Abrasion Test — Taber Abraser — Task 4

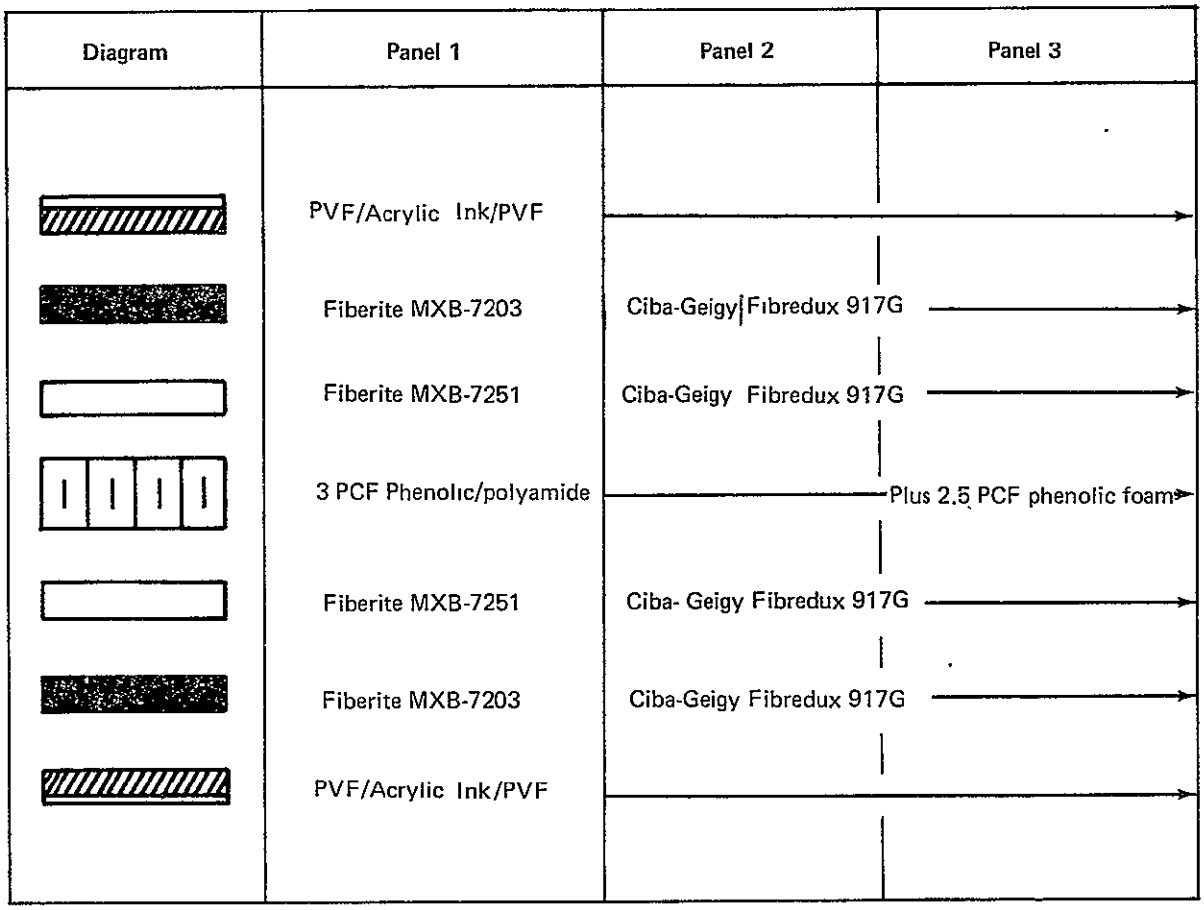


Figure 72.—Sandwich Panel Materials—Task 5

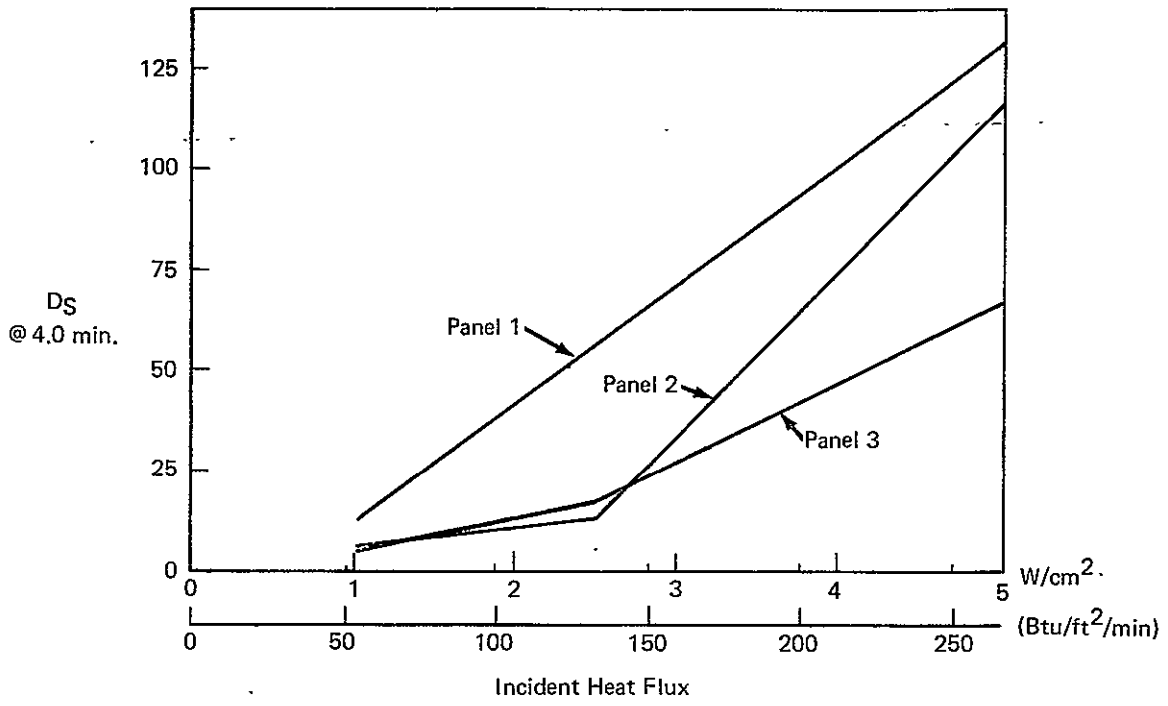


Figure 73. —Smoke Emission as Measured in the NBS Smoke Chamber — D_S — Flaming — Task 5

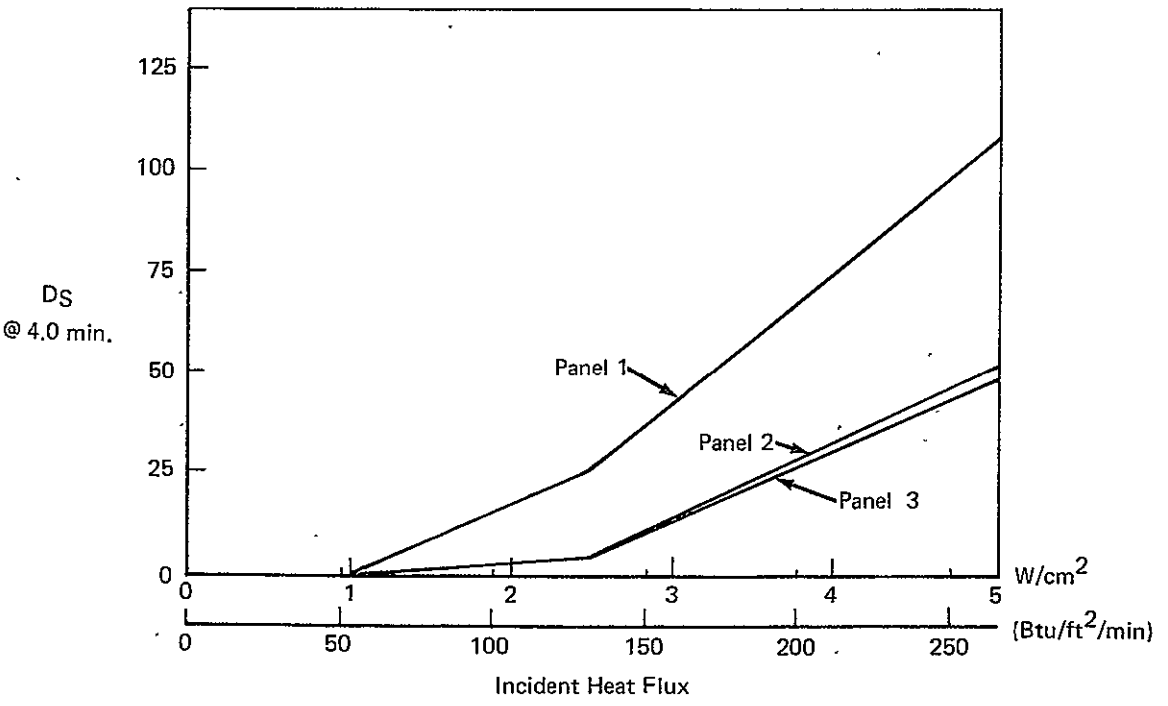


Figure 74. —Smoke Emission as Measured in the NBS Smoke Chamber — D_S — Smoldering — Task 5

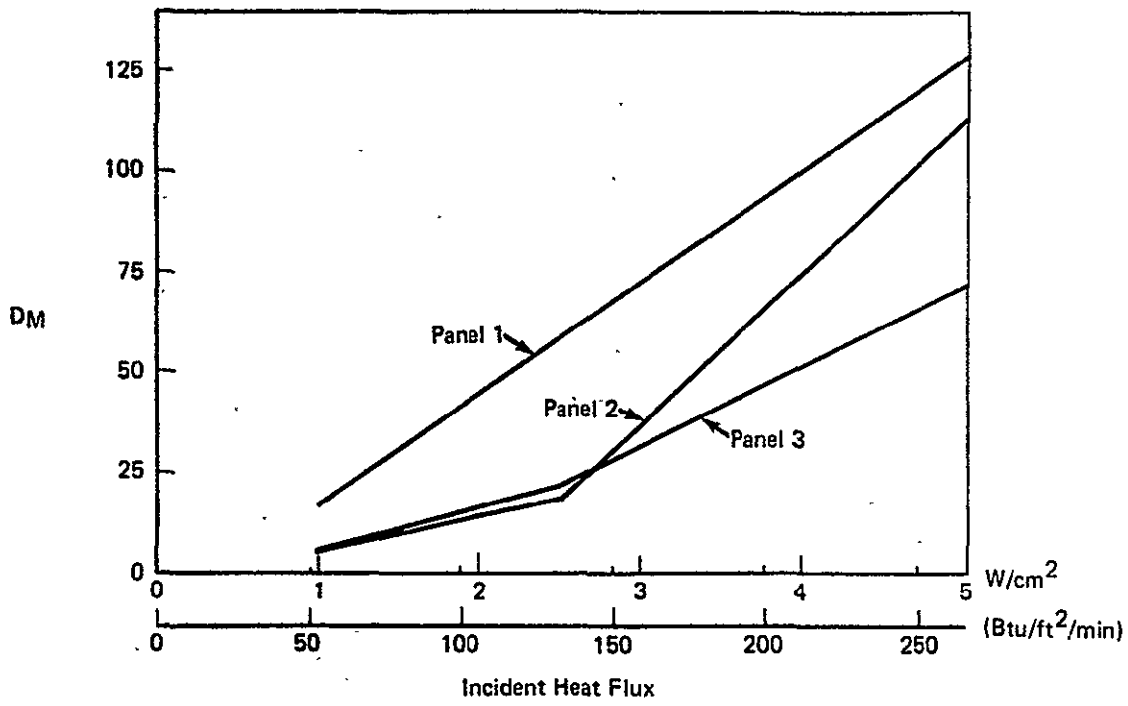


Figure 75. –Smoke Emission as Measured in the NBS Smoke Chamber – D_M – Flaming – Task 5

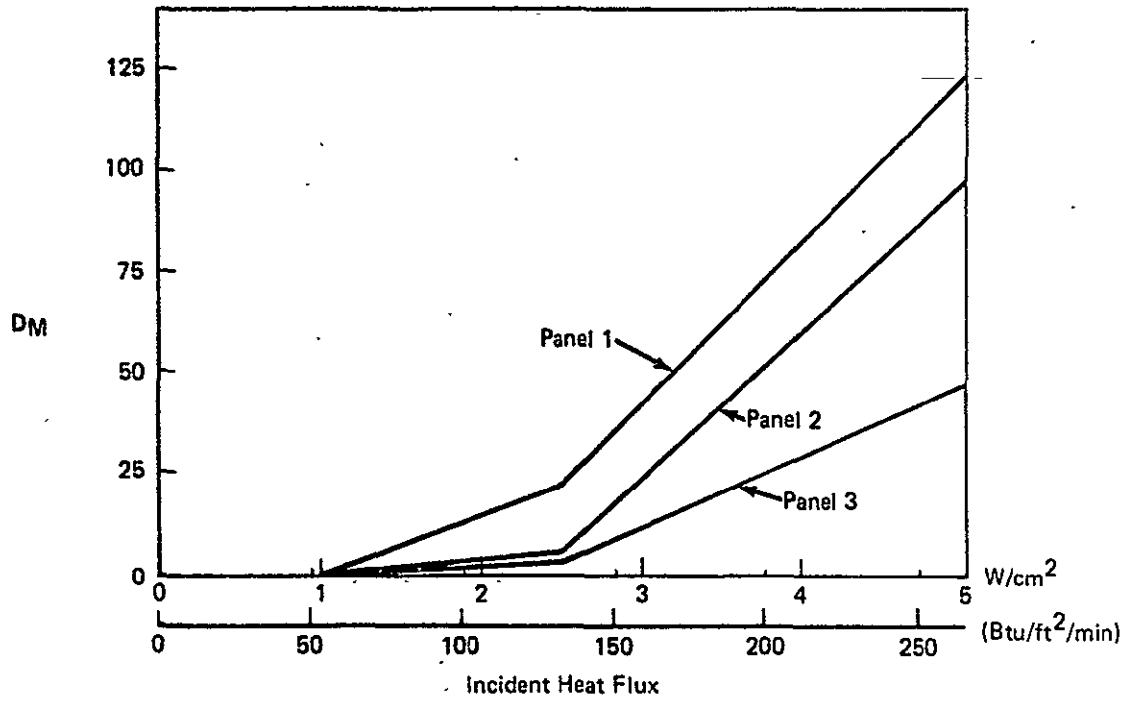


Figure 76. –Smoke Emission as Measured in the NBS Smoke Chamber – D_M – Smoldering – Task 5

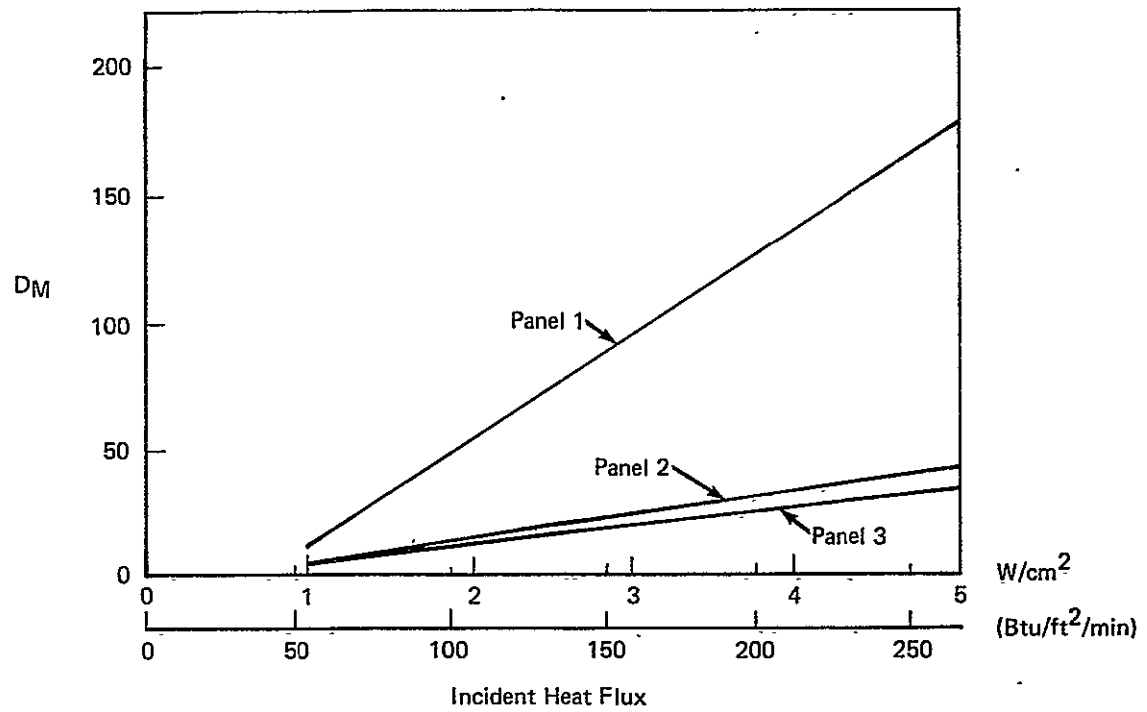


Figure 77. –Smoke Emission as Measured in the OSU Release Rate Apparatus — Vertical Flaming — D_M — Task 5

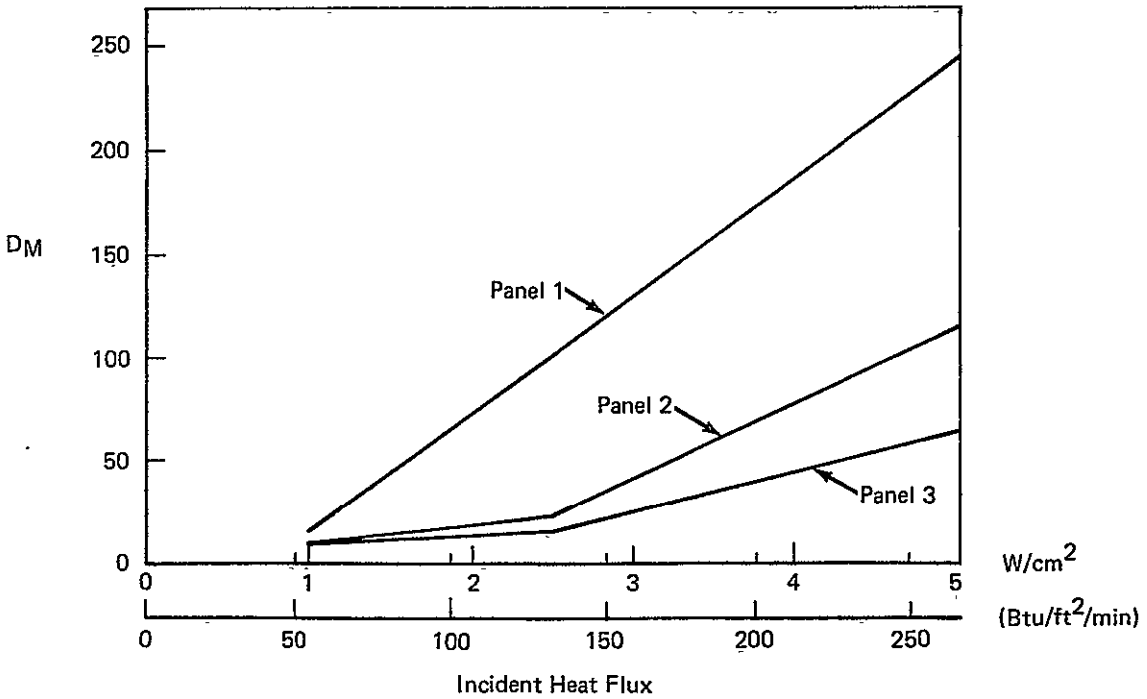


Figure 78. –Smoke Emission as Measured in the OSU Release Rate Apparatus — Horizontal Flaming — D_M — Task 5

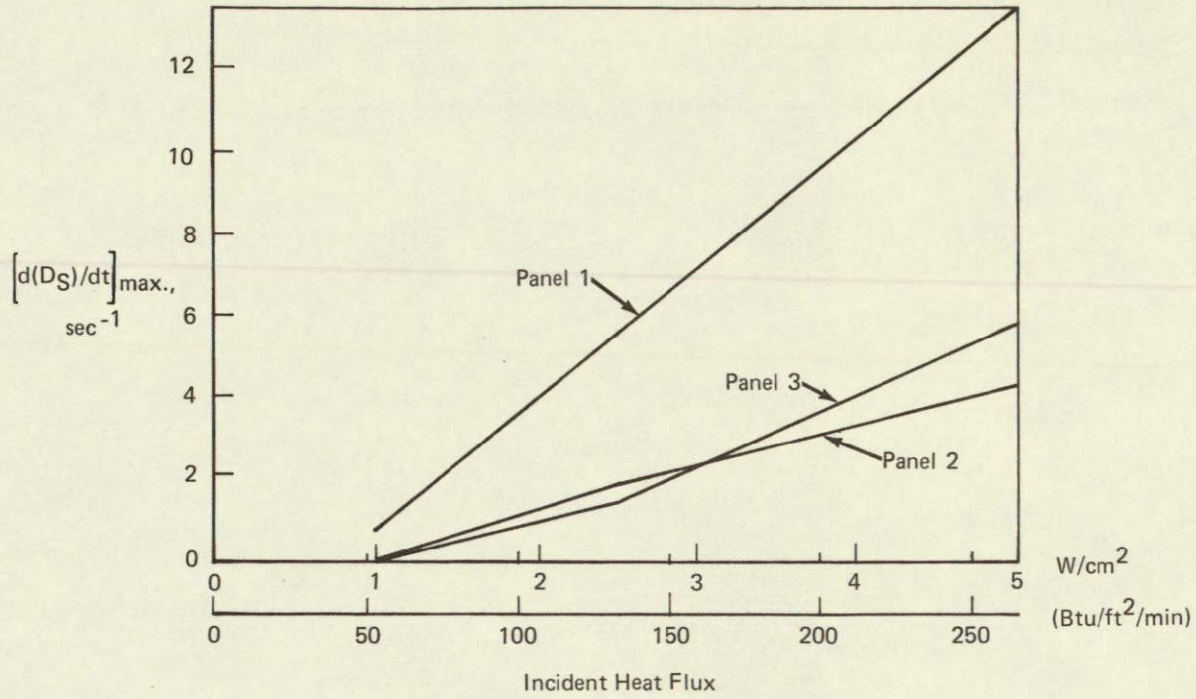


Figure 79. —Maximum Rate of Smoke Emission as Measured in the OSU Release Rate Apparatus — Vertical Flaming — Task 5

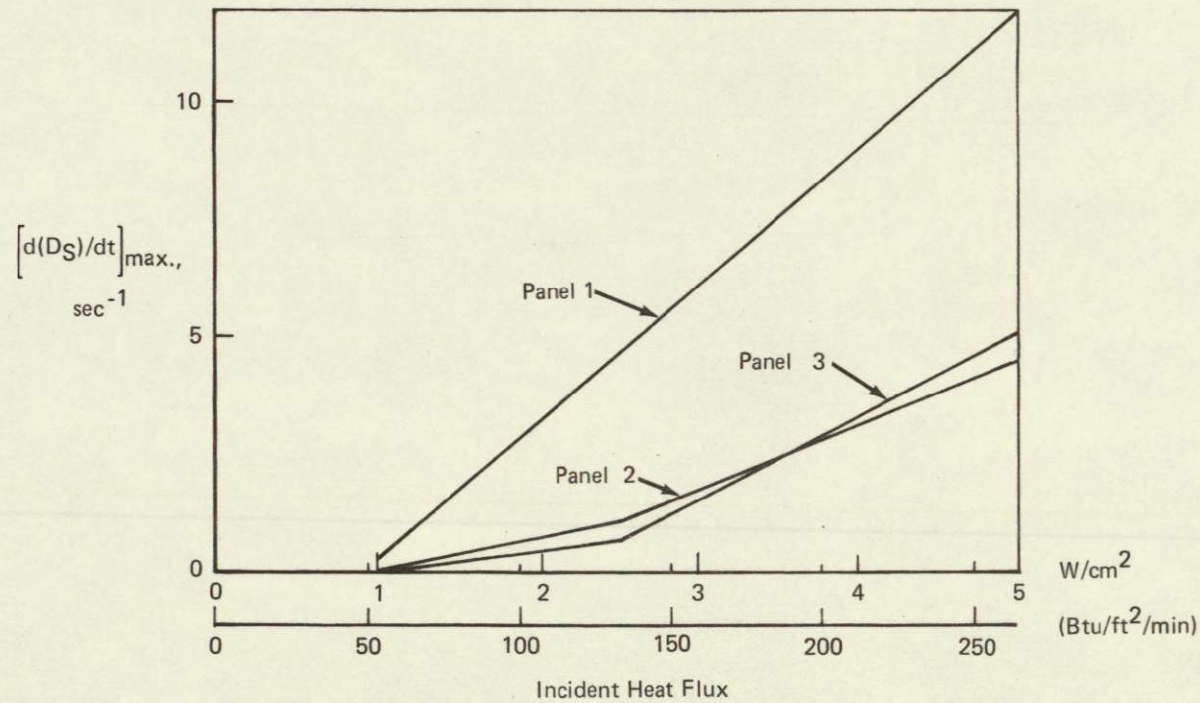


Figure 80. —Maximum Rate of Smoke Emission as Measured in the OSU Release Rate Apparatus — Horizontal Flaming — Task 5

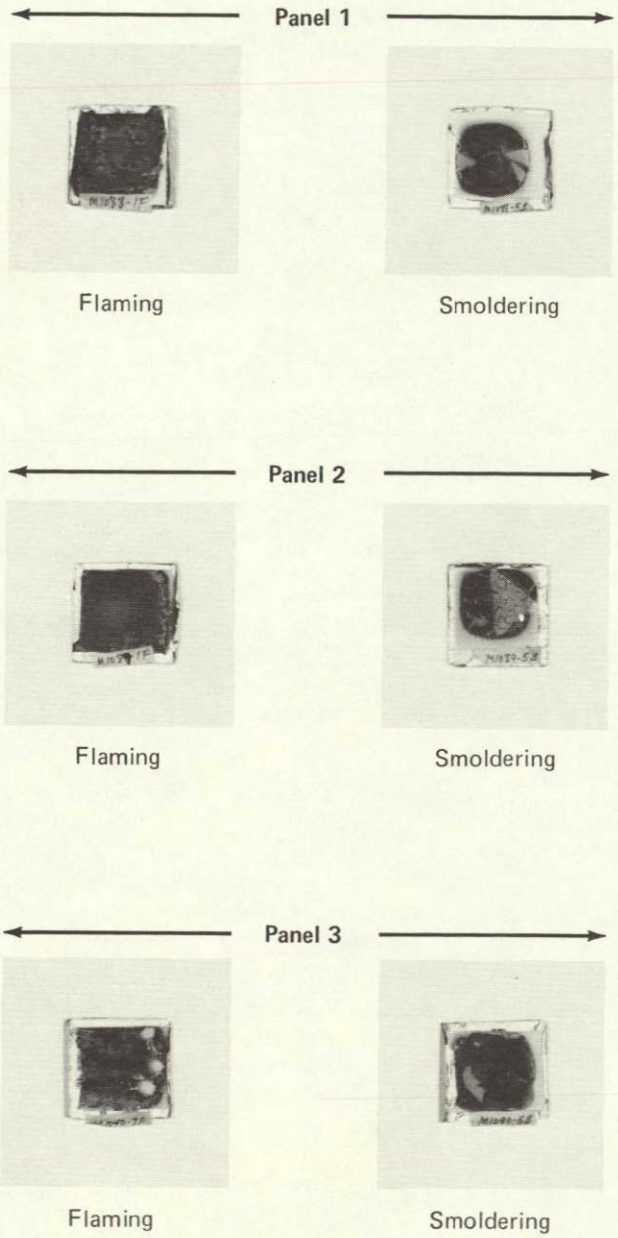


Figure 81.—NBS Smoke Chamber Test Specimens—1.0 W/cm^2 (Task 5)

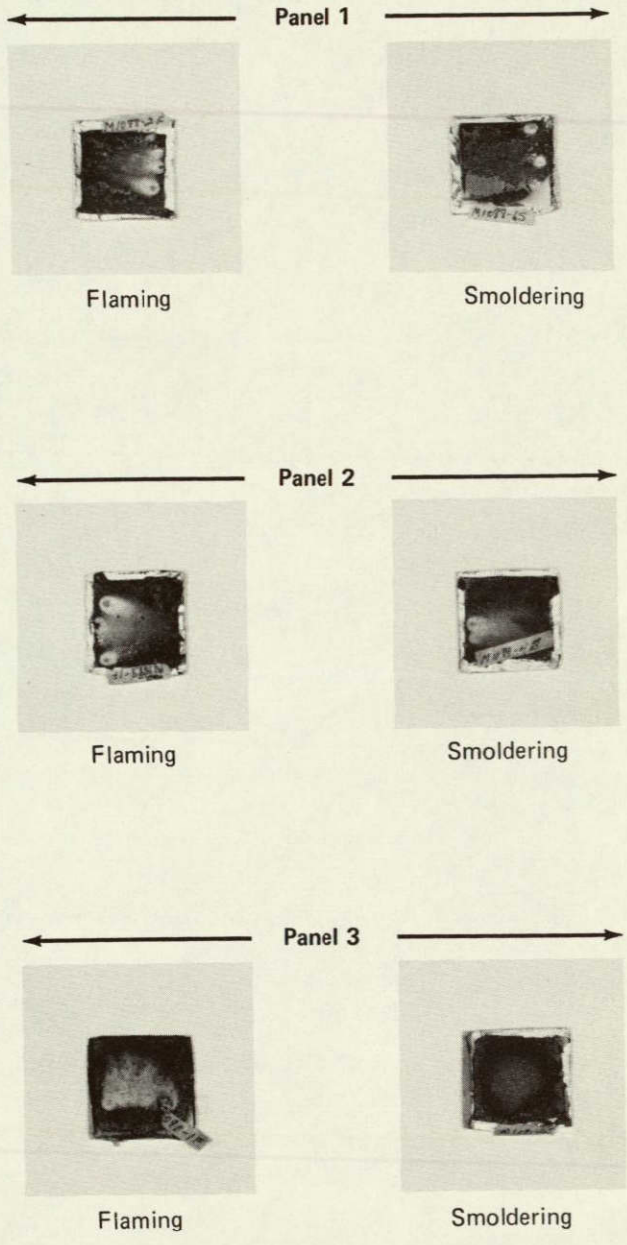
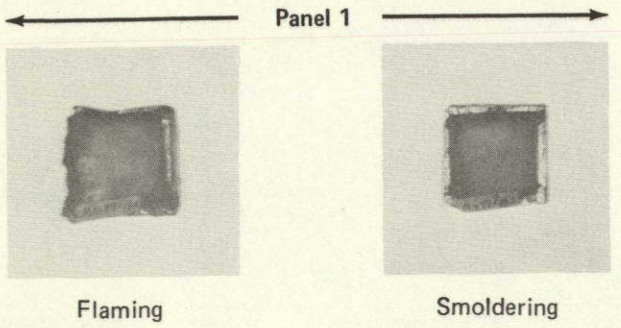
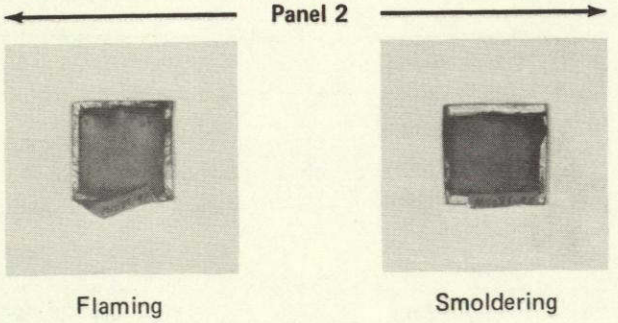


Figure 82.—NBS Smoke Chamber Test Specimens—2.5 W/cm^2 (Task 5)





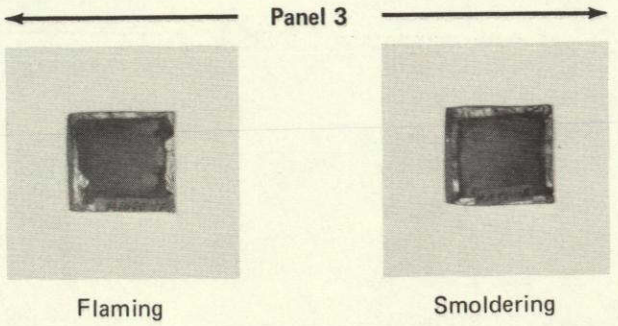


Figure 83.—NBS Smoke Chamber Test Specimens—5.0 W/cm^2 (Task 5)

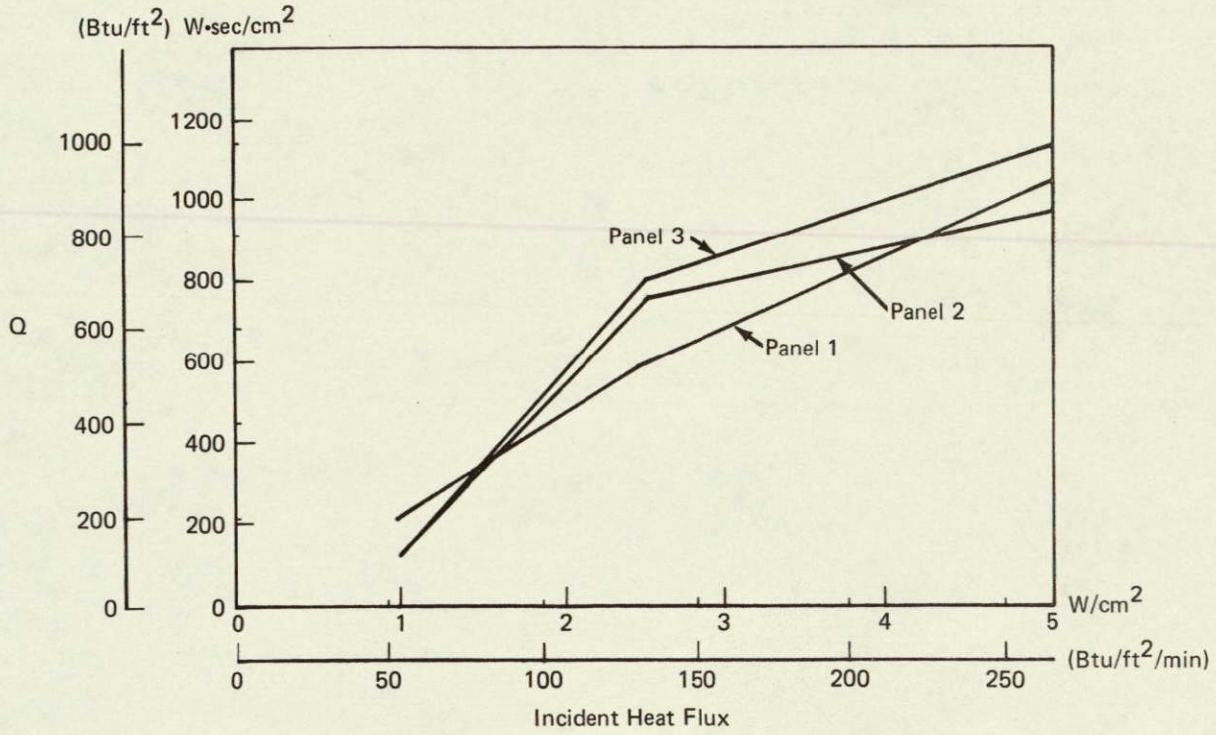


Figure 84. –Heat Release as Measured in the OSU Release Rate Apparatus – Vertical Flaming – Task 5

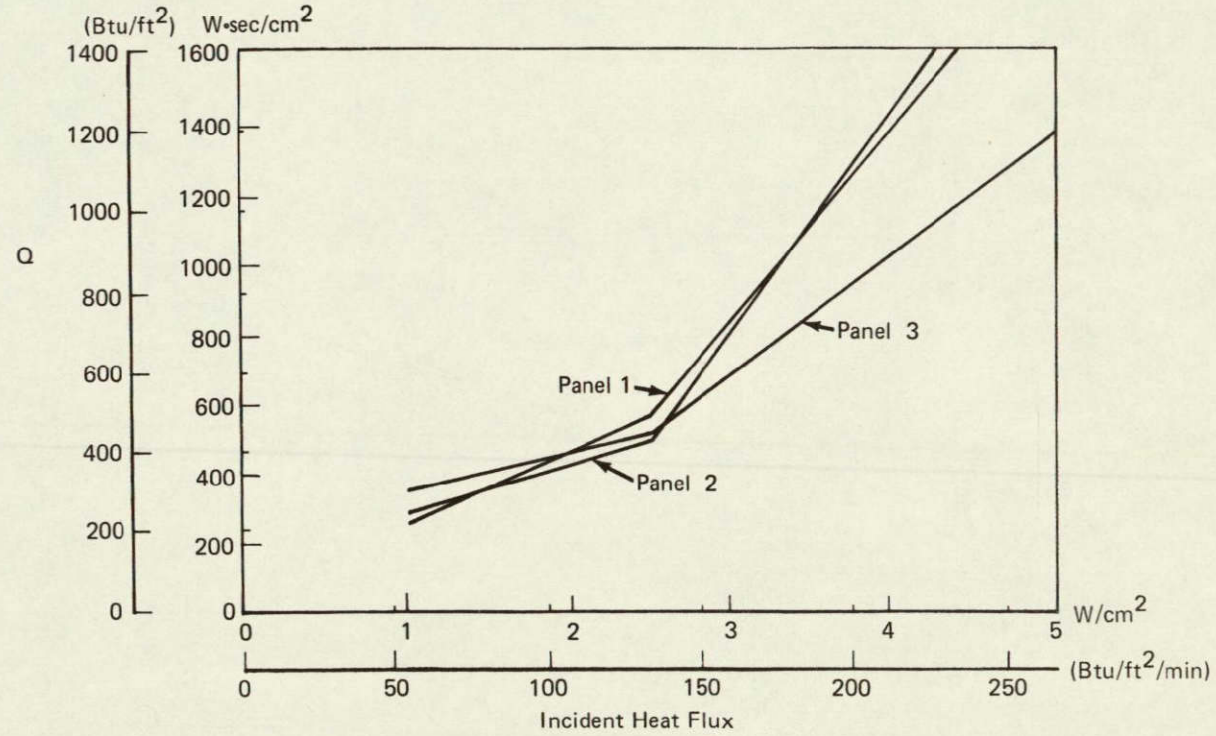


Figure 85. –Heat Release as Measured in the OSU Release Rate Apparatus – Horizontal Flaming – Task 5

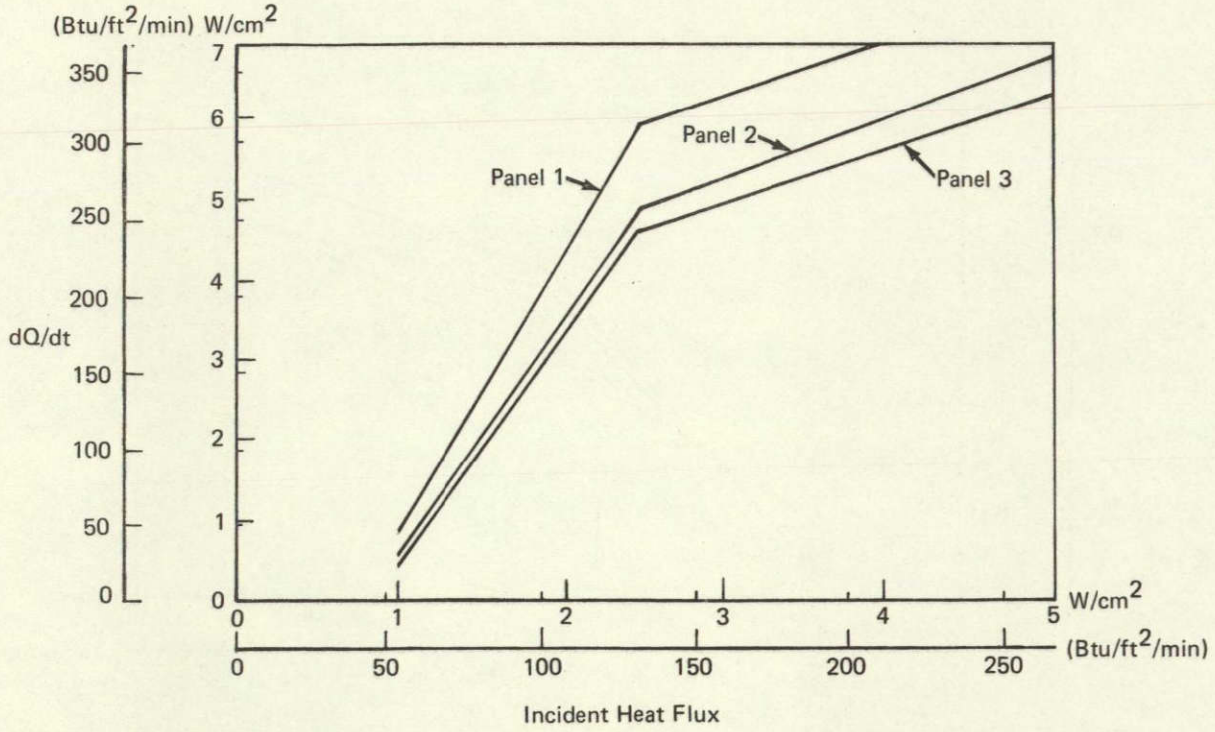


Figure 86. —Heat Release Rate as Measured in the OSU Release Rate Apparatus — Vertical Flaming — Task 5

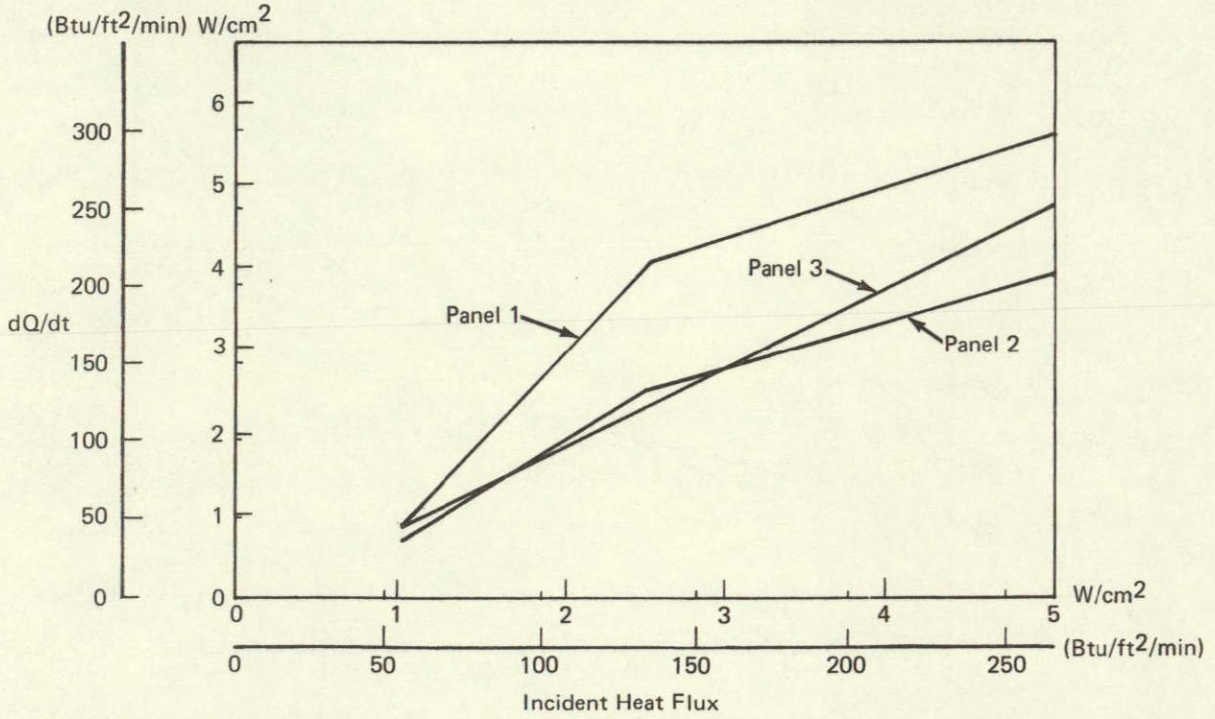


Figure 87. —Heat Release Rate as Measured in the OSU Release Rate Apparatus — Horizontal Flaming — Task 5

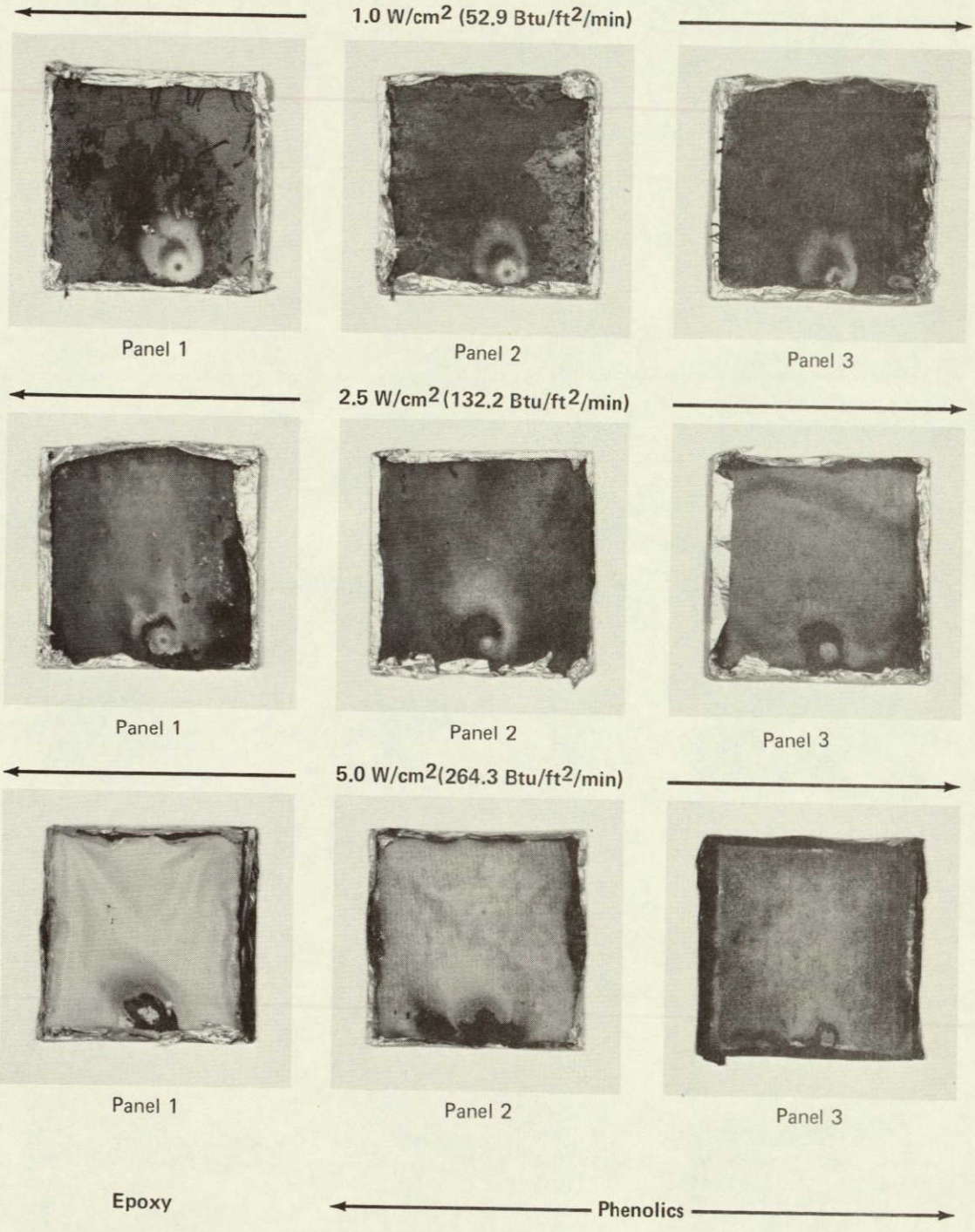


Figure 88.—OSU Heat Release Test Specimens—Vertical (Task 5)

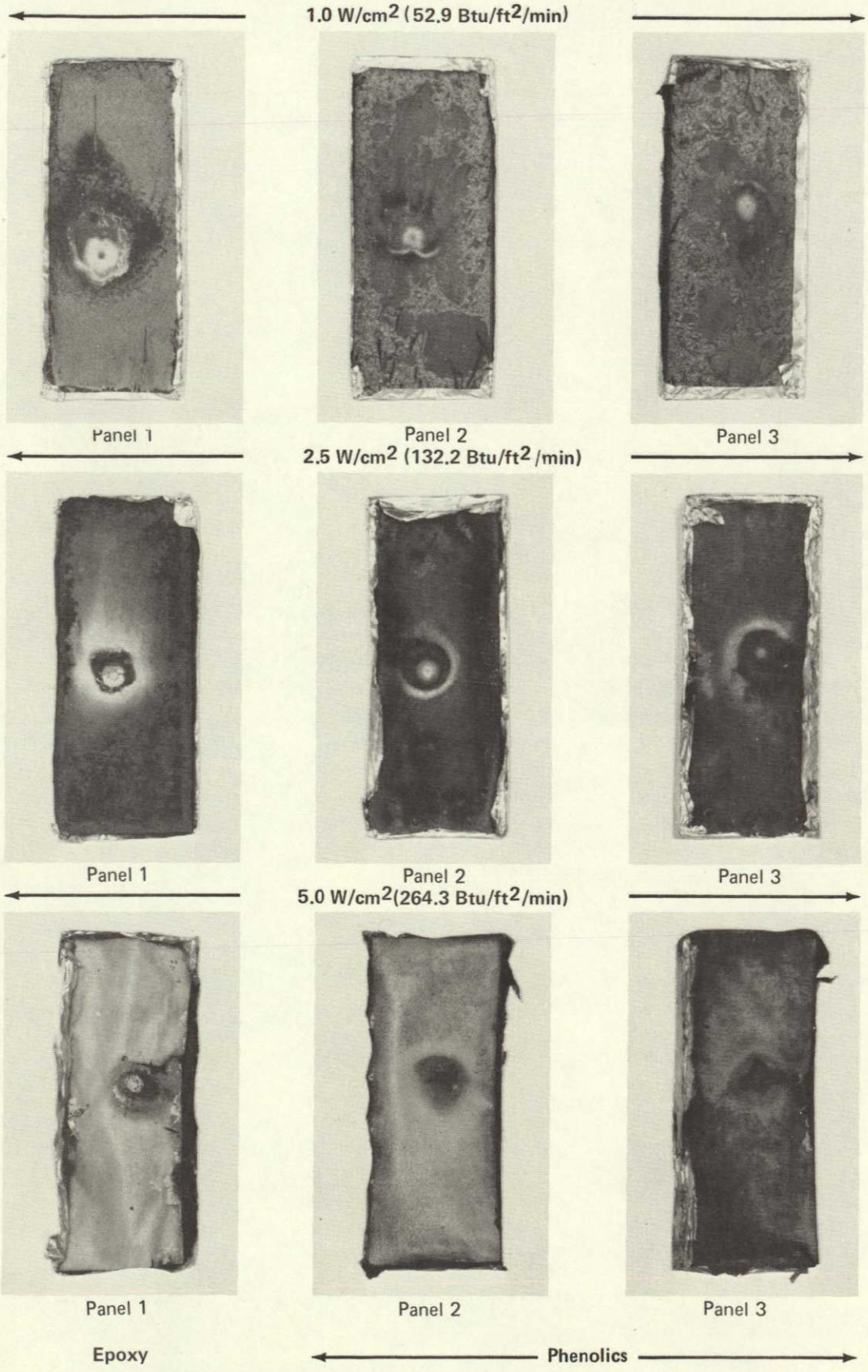


Figure 89.—OSU Heat Release Test Specimens—Horizontal (Task 5)

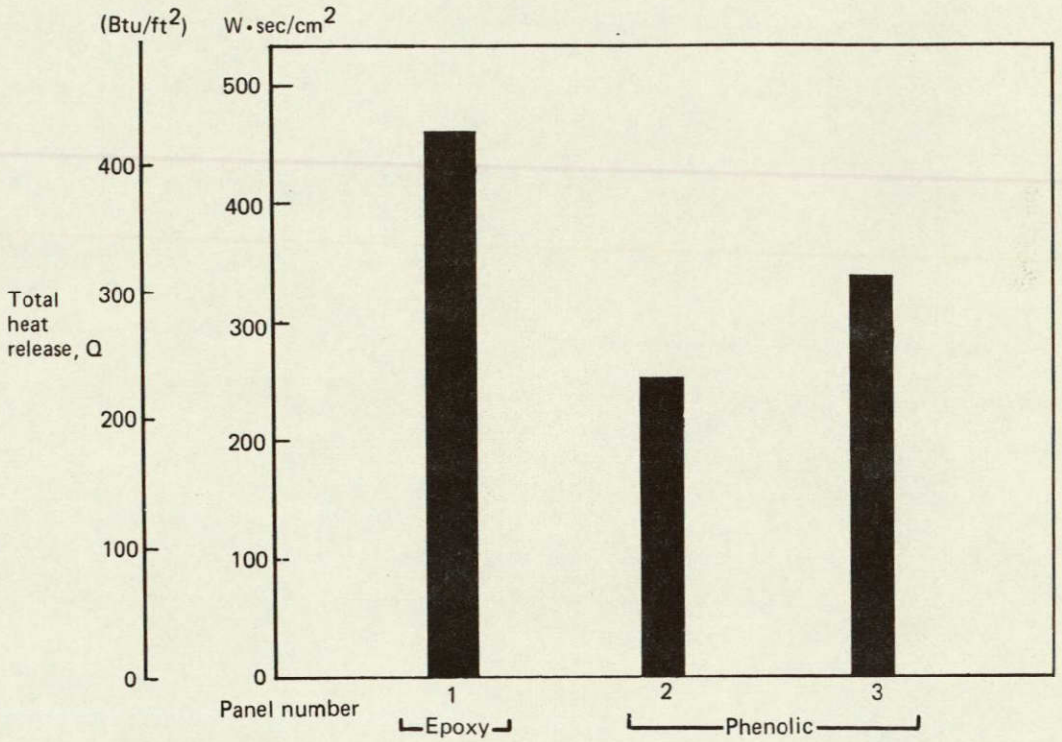


Figure 90.—Heat Release as Measured in the Boeing Burn Through Apparatus — Task 5

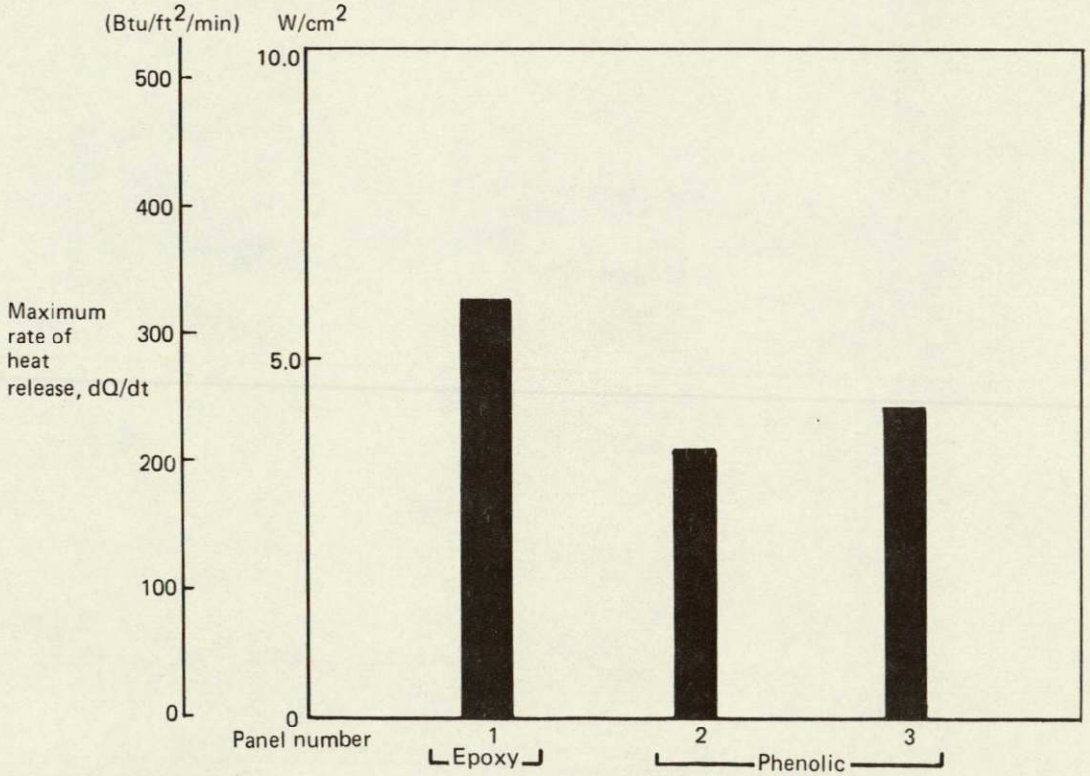


Figure 91.—Heat Release Rate as Measured in the Boeing Burn Through Apparatus — Task 5

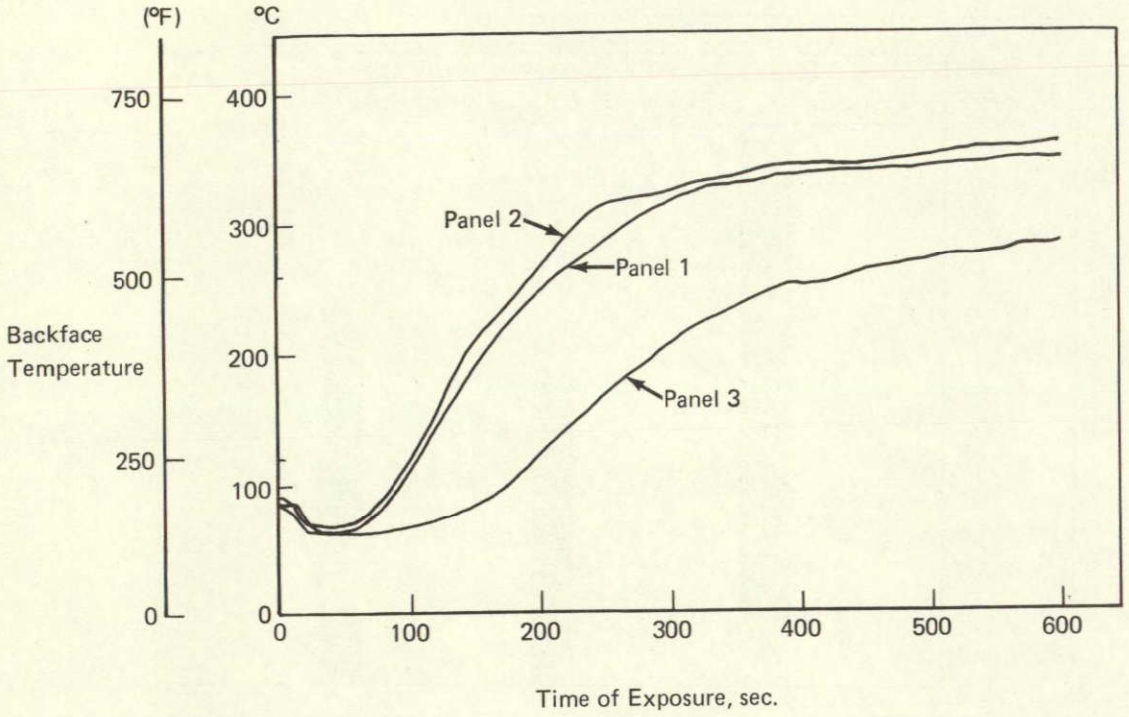


Figure 92. –Backface Temperature Versus Time – Boeing Burn Through Apparatus – Task 5

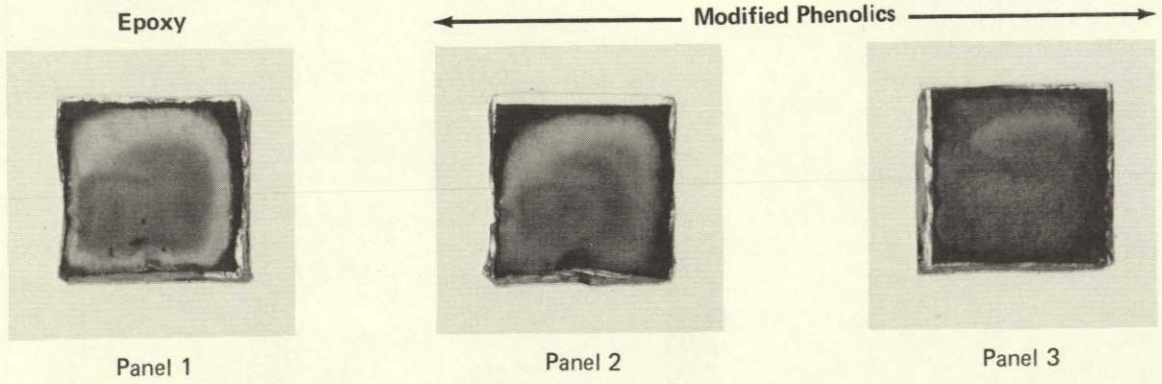


Figure 93.–Boeing Burn Through Test Specimens– Task 5

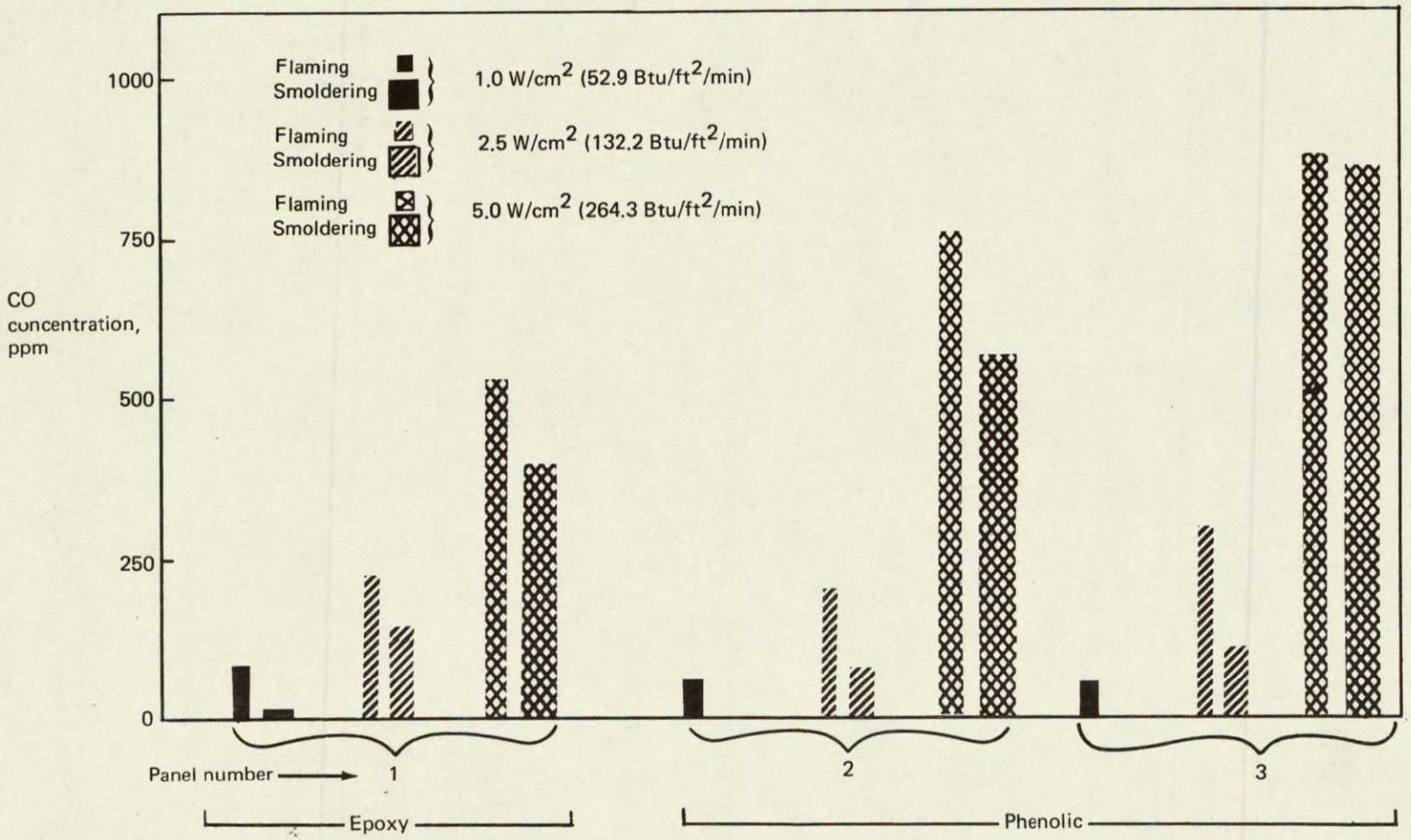


Figure 94.—CO Evolution as Measured in the NBS Smoke Chamber — 4.0 Minute Sample — Task 5

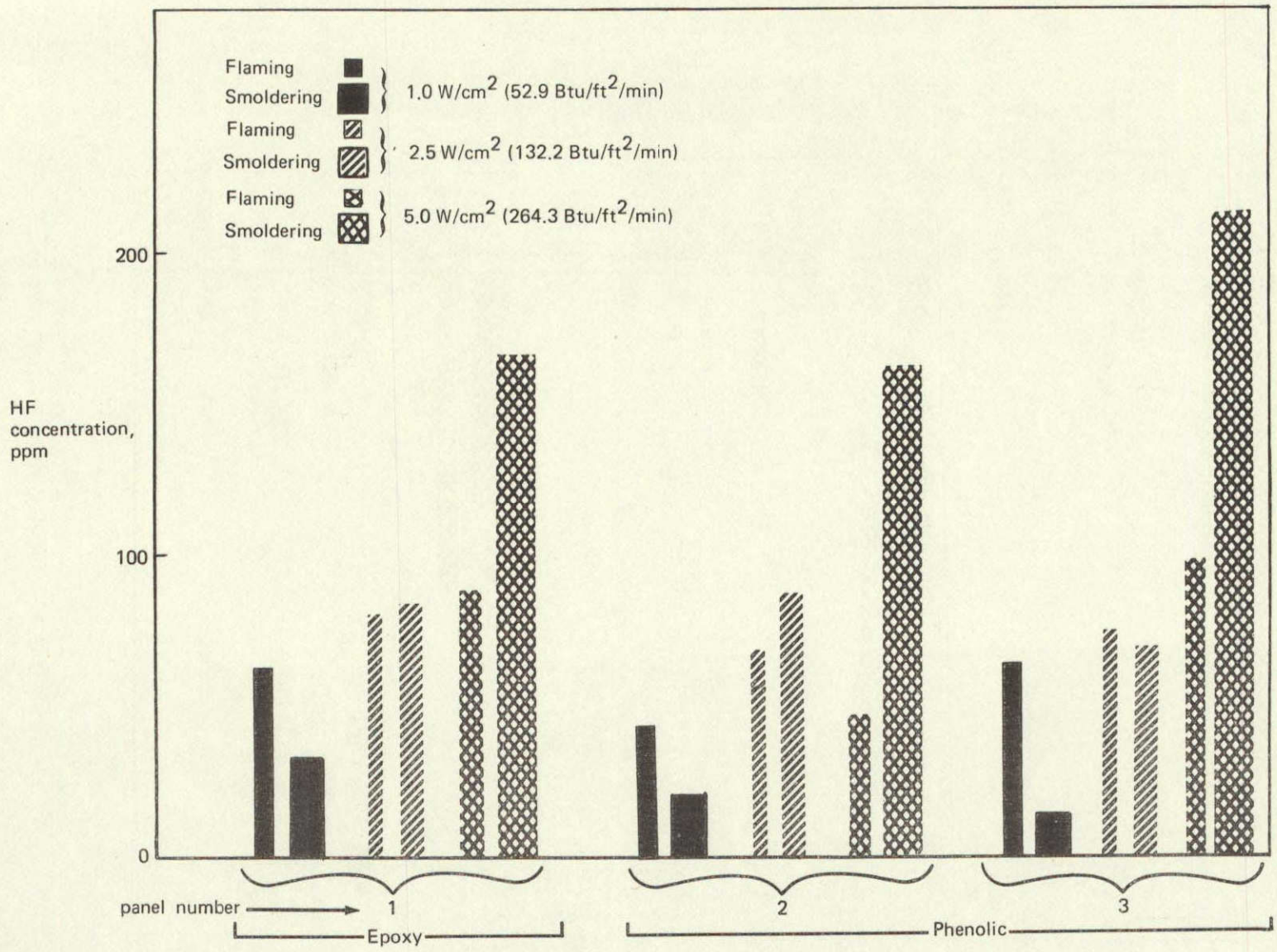


Figure 95.—HF Evolution as Measured in the NBS Smoke Chamber — 4.0 Minute Sample — Task 5

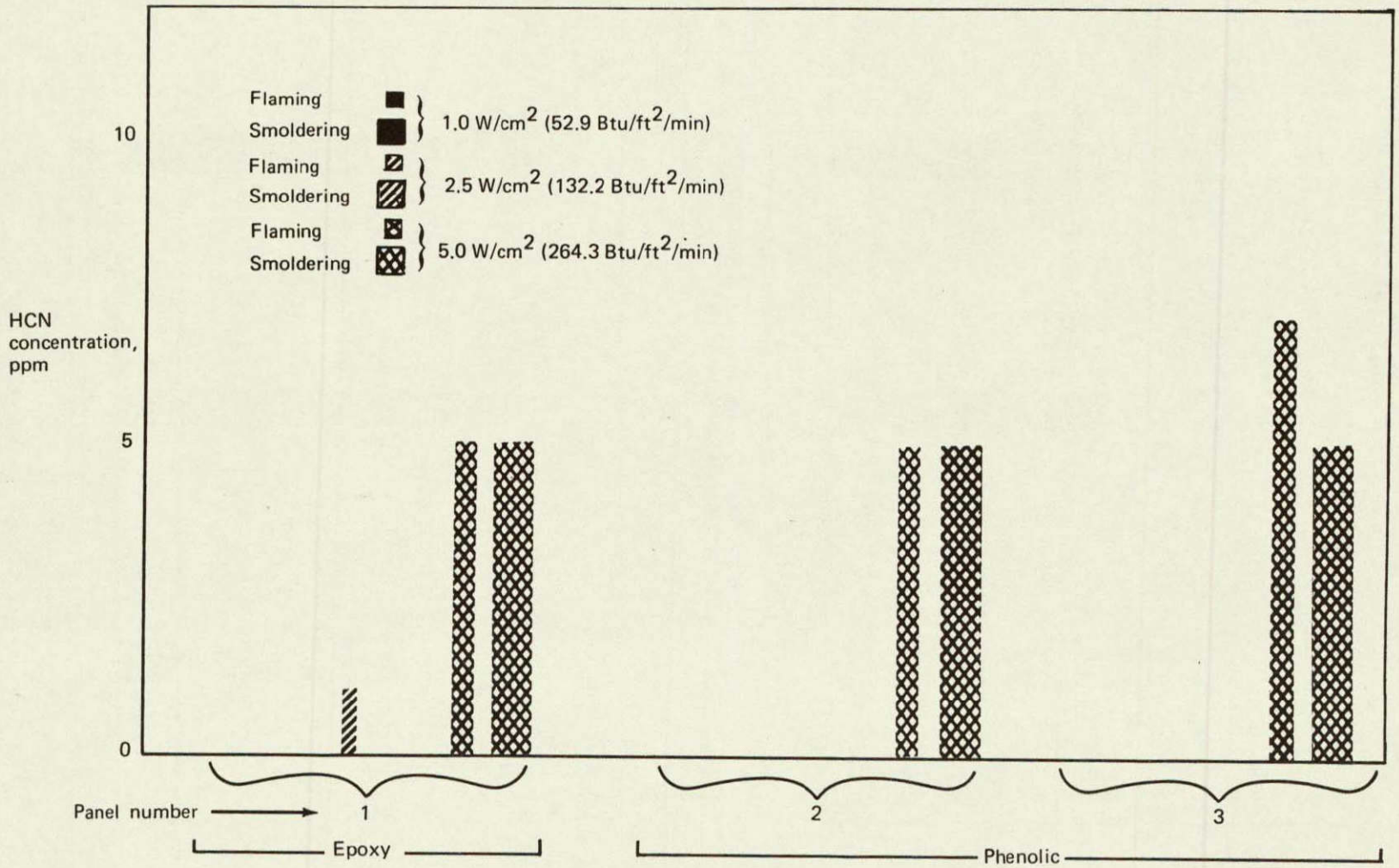


Figure 96.—HCN Evolution as Measured in the NBS Smoke Chamber — 4.0 Minute Sample — Task 5

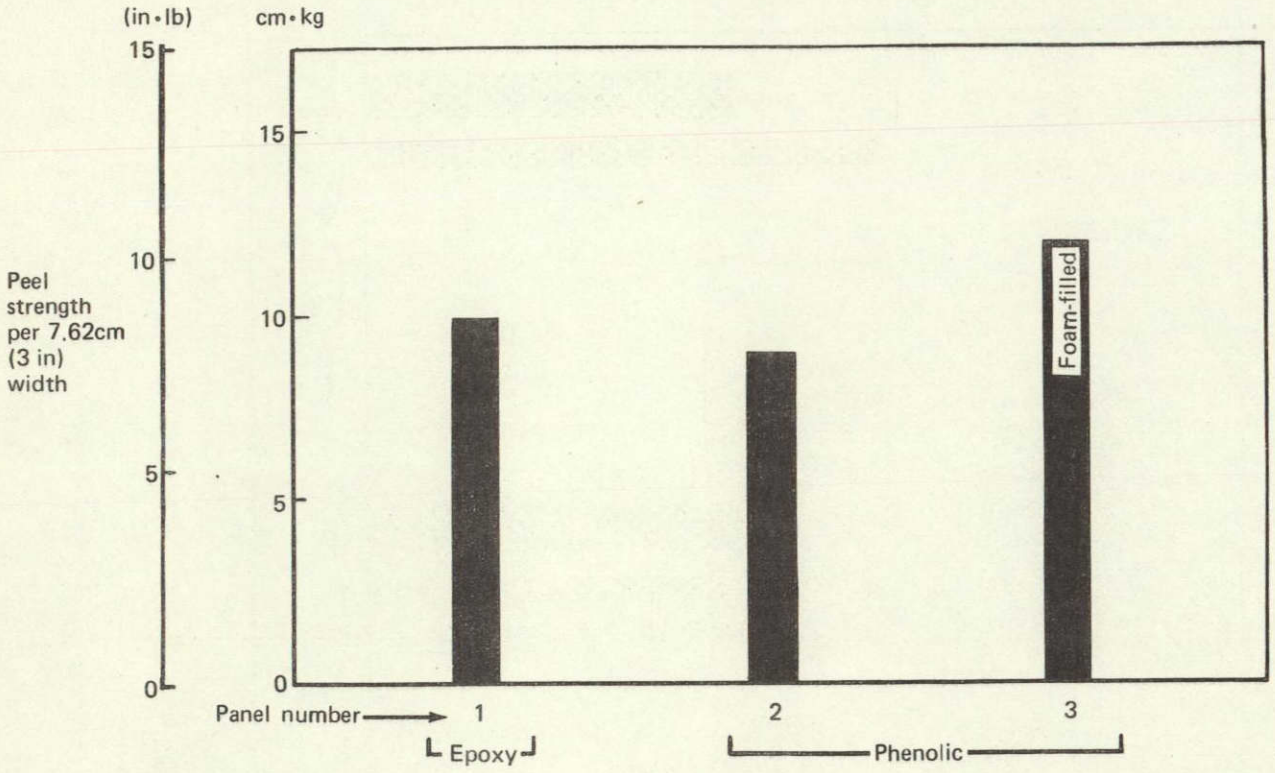


Figure 97.—Peel Strength — Task 5

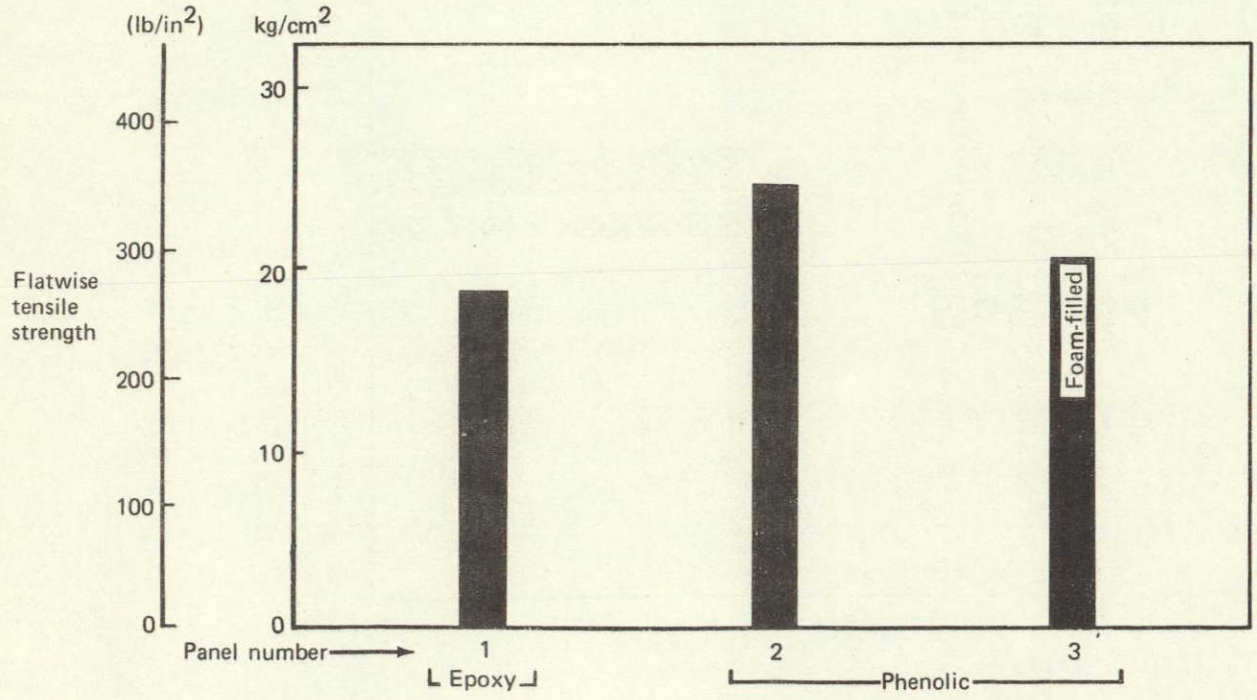
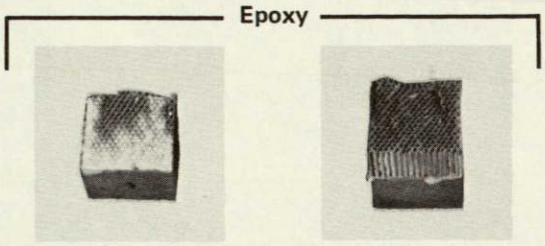


Figure 98.—Flatwise Tensile Strength — Task 5



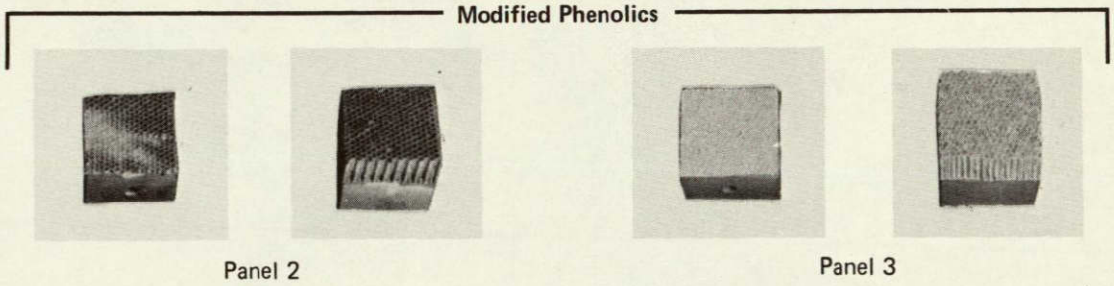


Figure 99.—Flatwise Tensile Test Specimens (Task 5)

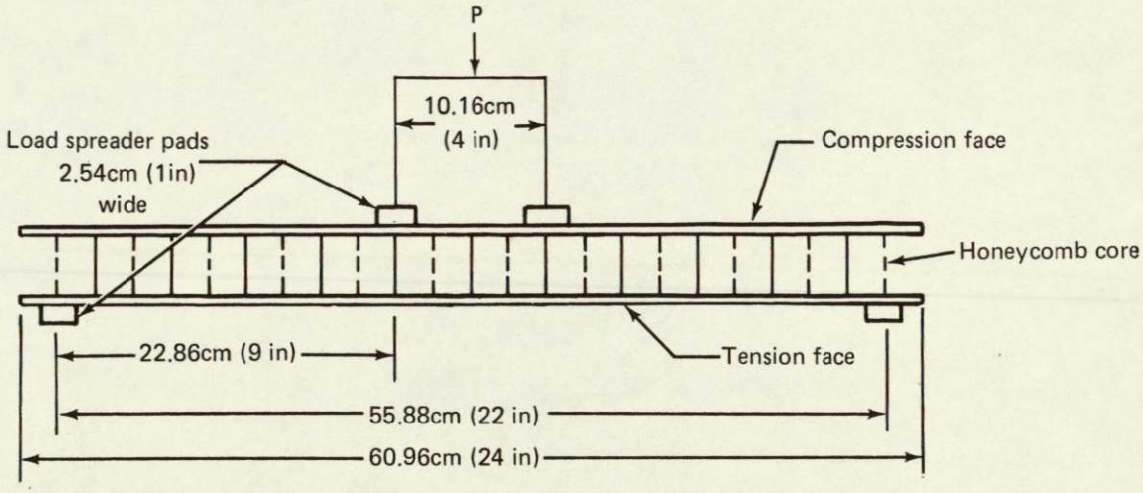


Figure 100.—Beam Flexure Test Setup

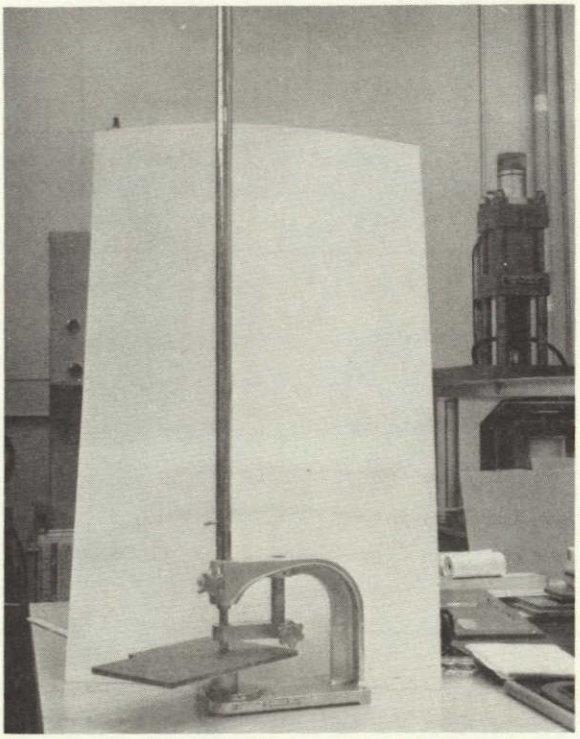


Figure 101.—Gardener Impact Test Fixture

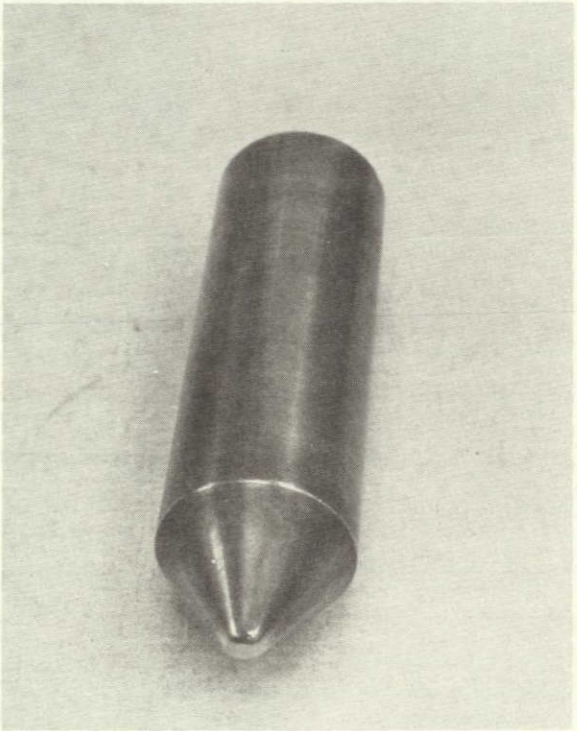


Figure 102.—Impact Test Point